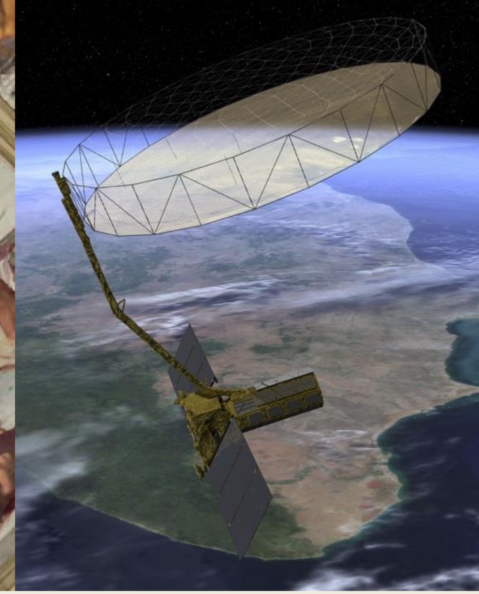
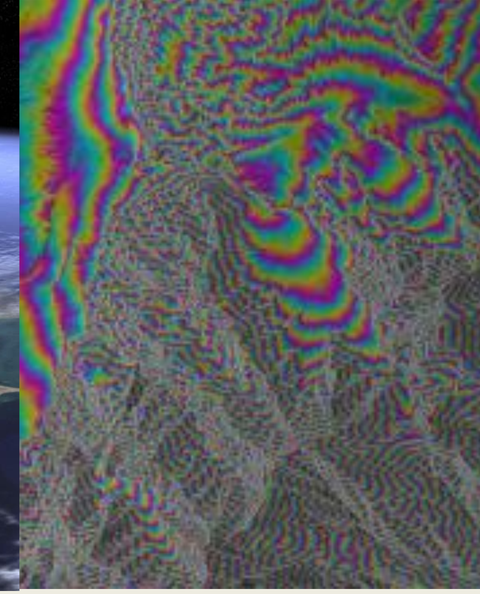


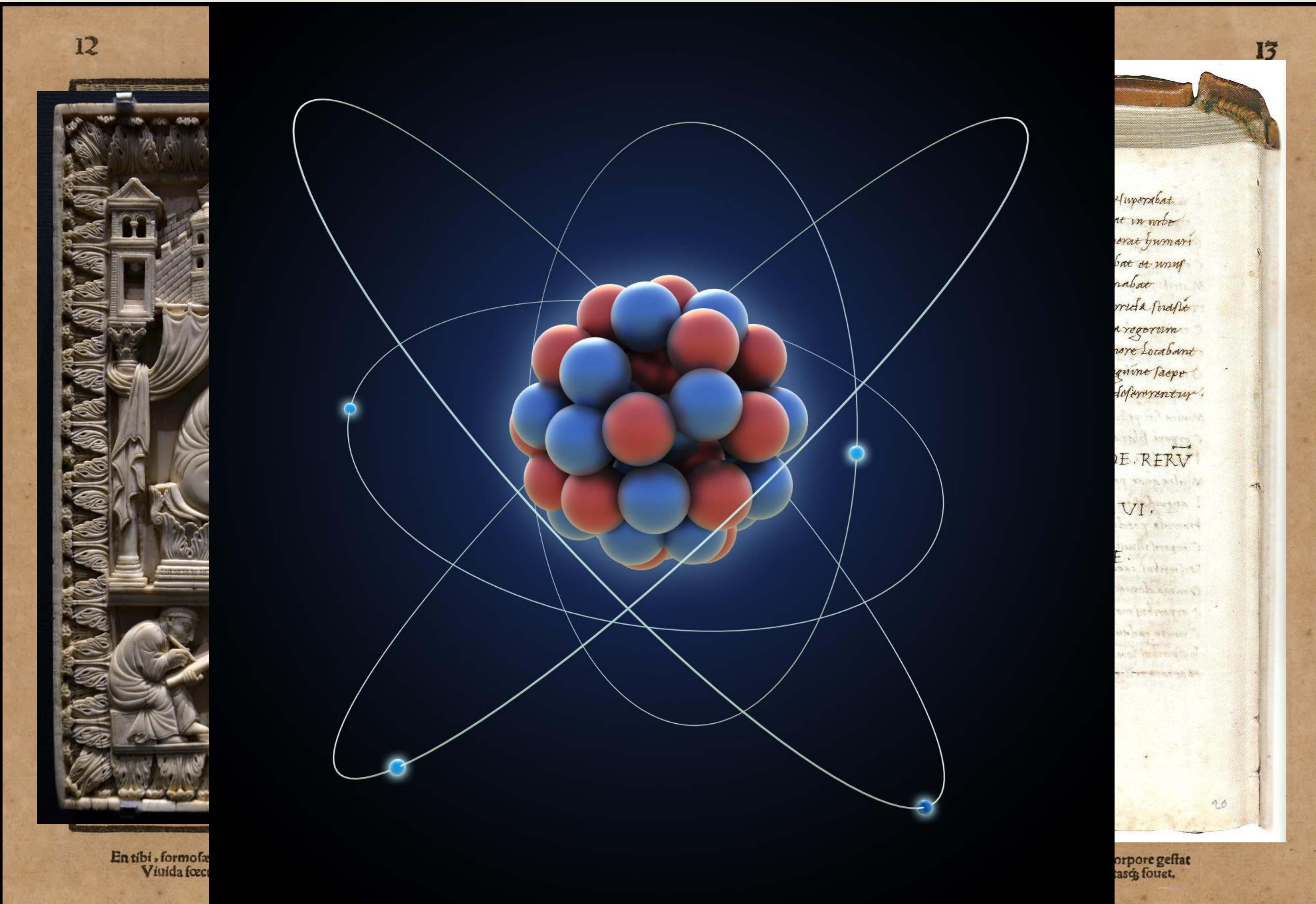



The Renaissance in Radar Remote Sensing

Our New Vision for Earth and the Planets

Paul A Rosen, Jet Propulsion Laboratory, California Institute of Technology

JPL



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Why a Renaissance for Radar?

- **Rebirth** of what were essentially military techniques and technology in the context of remote sensing through their rediscovery or reinvention
- **Spirit** of rejuvenation, enthusiasm, and experimentation
- **Transformation** of radar from specialists tool to explosive use throughout science and applications
- Radar remote sensing attracts **Renaissance Men and Women**, poised to link the technologies to the applications

Outline

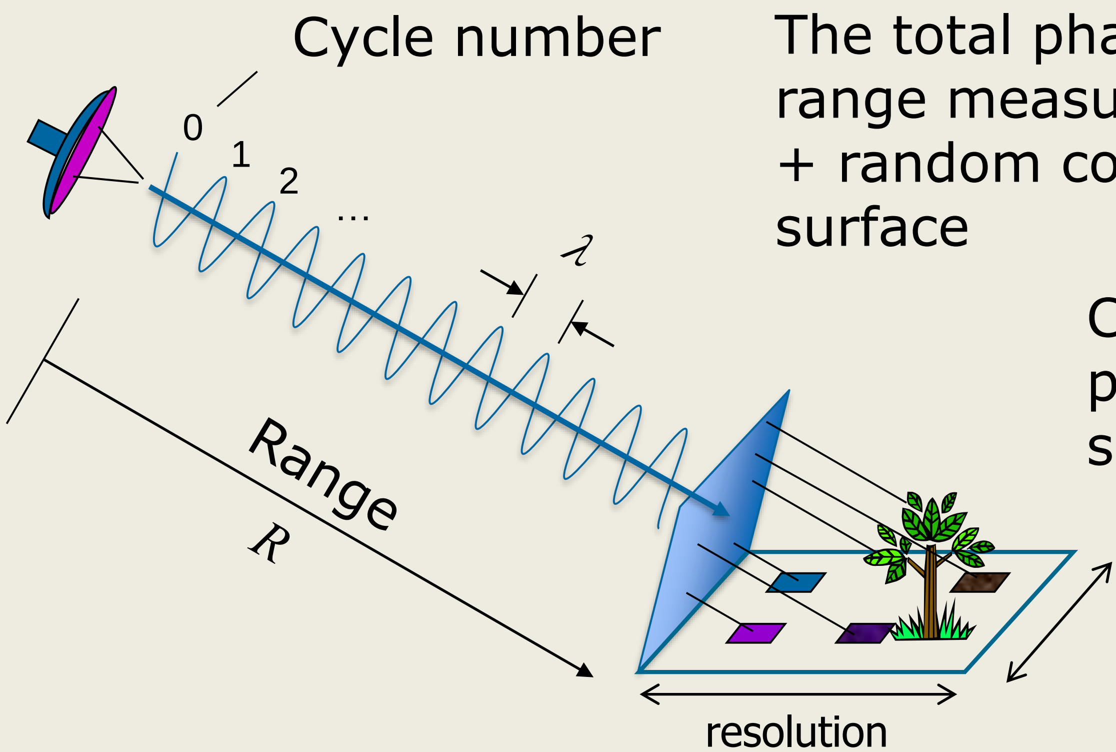
- Why Radar Remote Sensing?
- Developmental Perspective on Observations and Systems
  - Planetary
  - Earth
- Enabling Technologies
- Future Directions

Radar Phenomenology

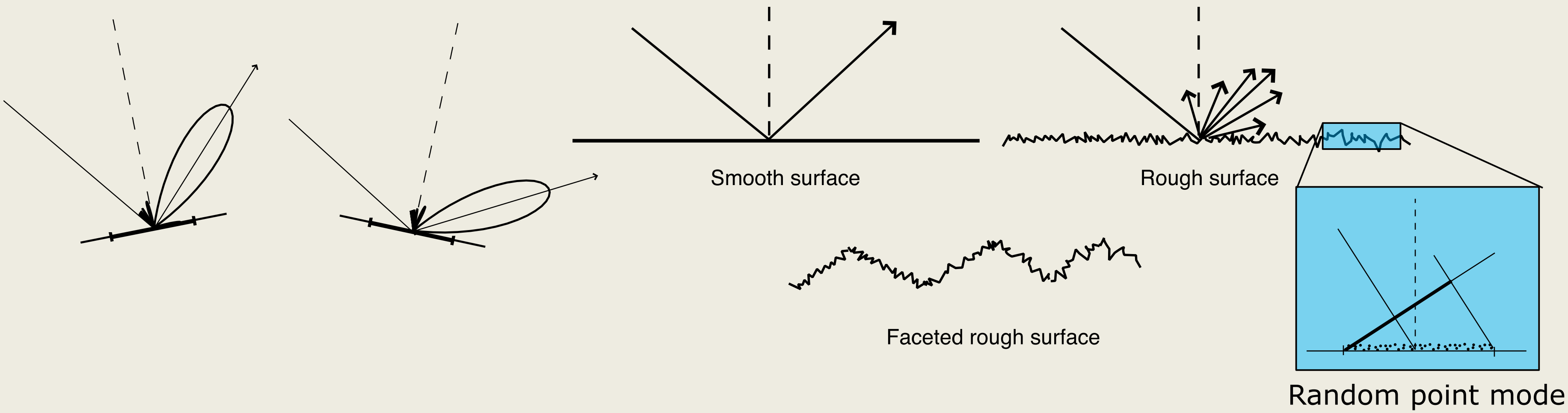
The radar view of the surface depends on the design features of the radar – its wavelength, polarization, resolution, and phase characteristics

The total phase is two-way range measured in wave cycles + random component from the surface

Collection of random path lengths and scatterer contributions

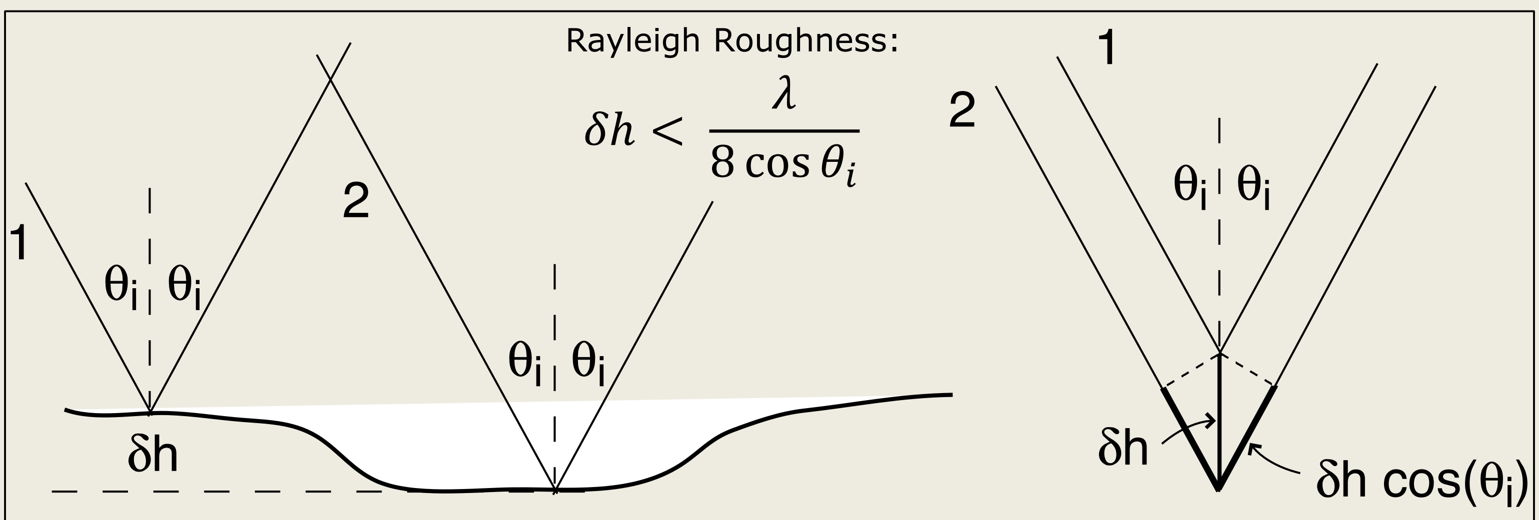


Surface and Volume Scattering for Radar

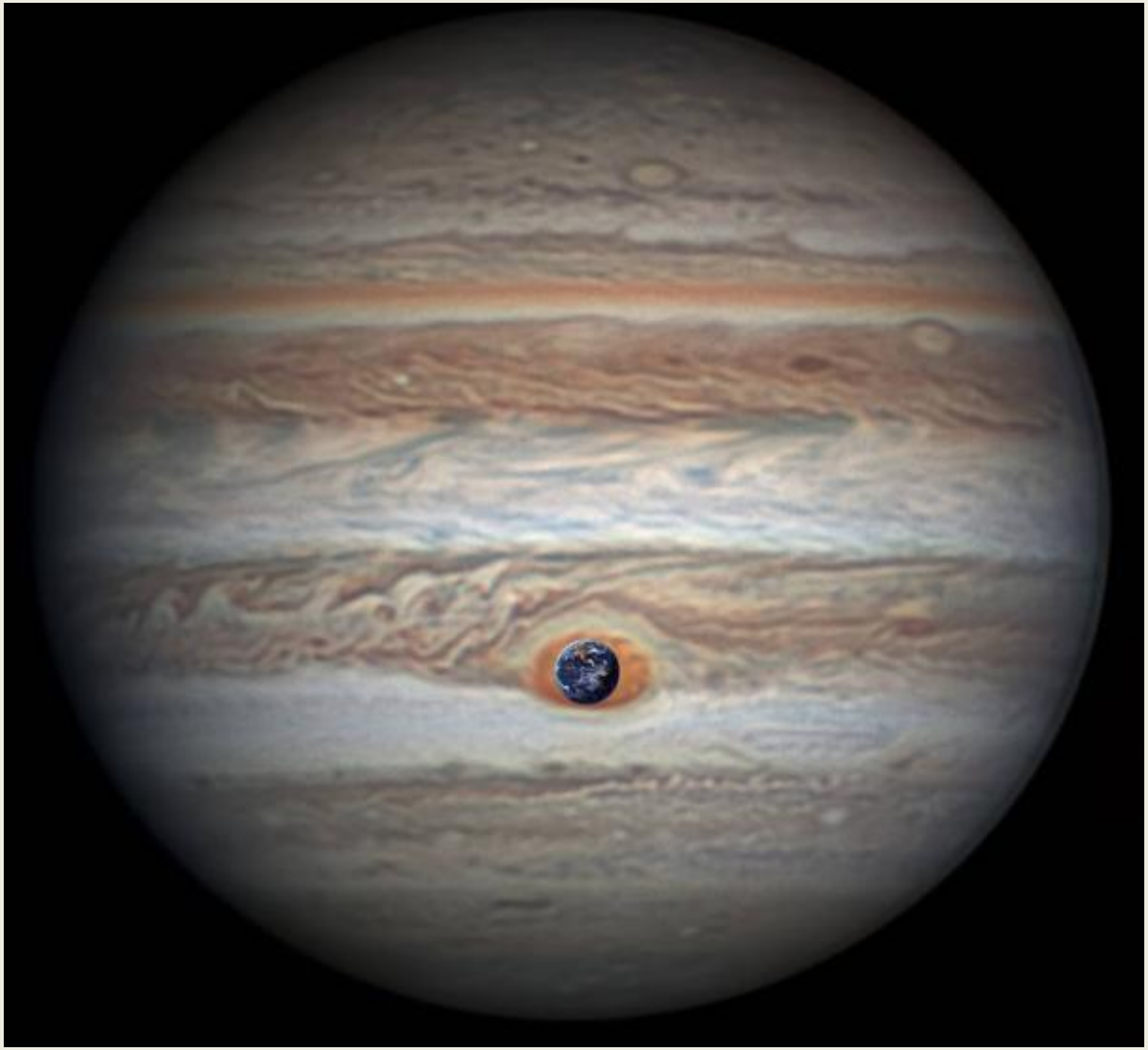


Rayleigh Roughness:

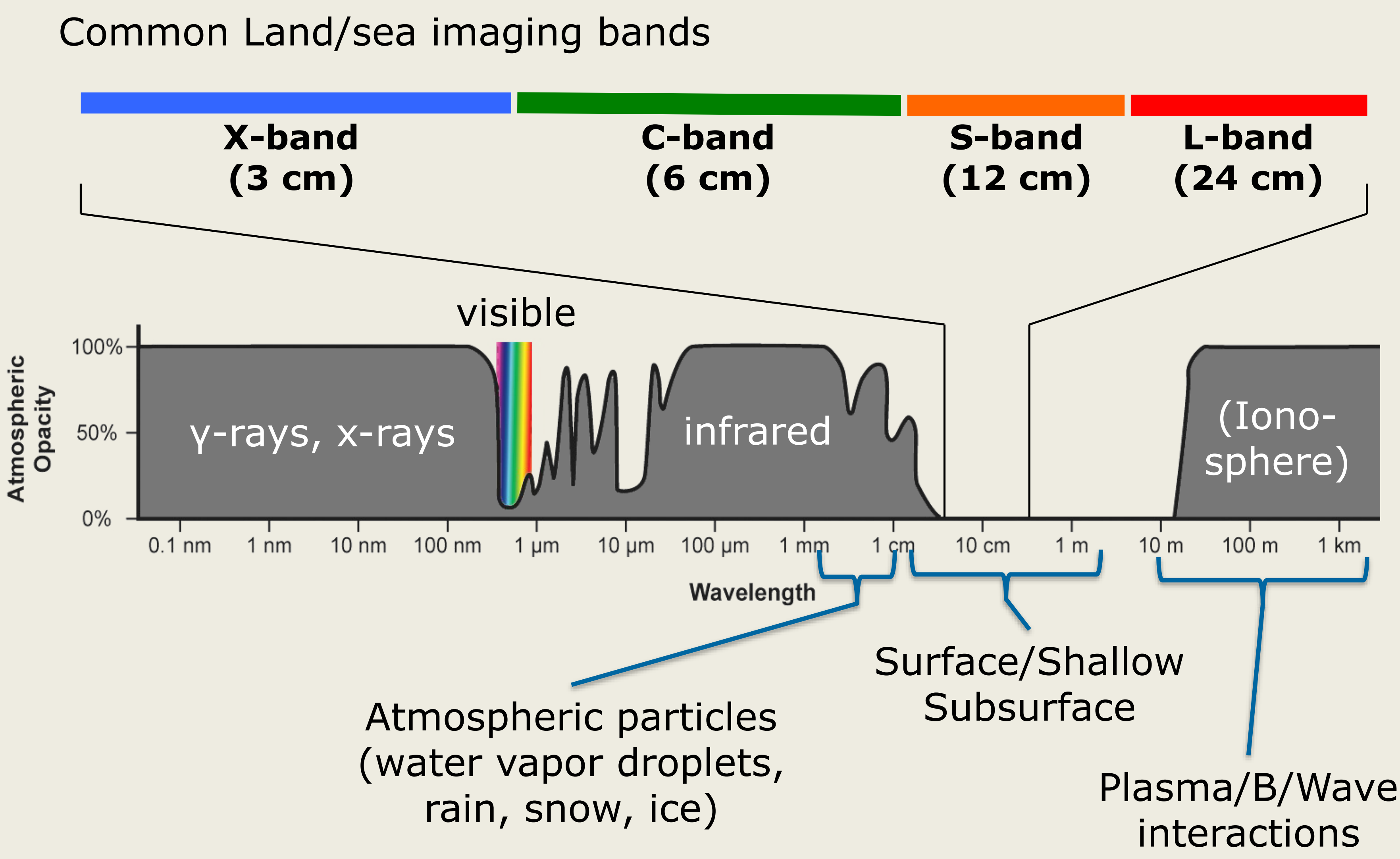
$$\delta h < \frac{\lambda}{8\cos\theta_i}$$



The Tyranny of Optical Remote Sensing



Atmospheric Windows and Radar



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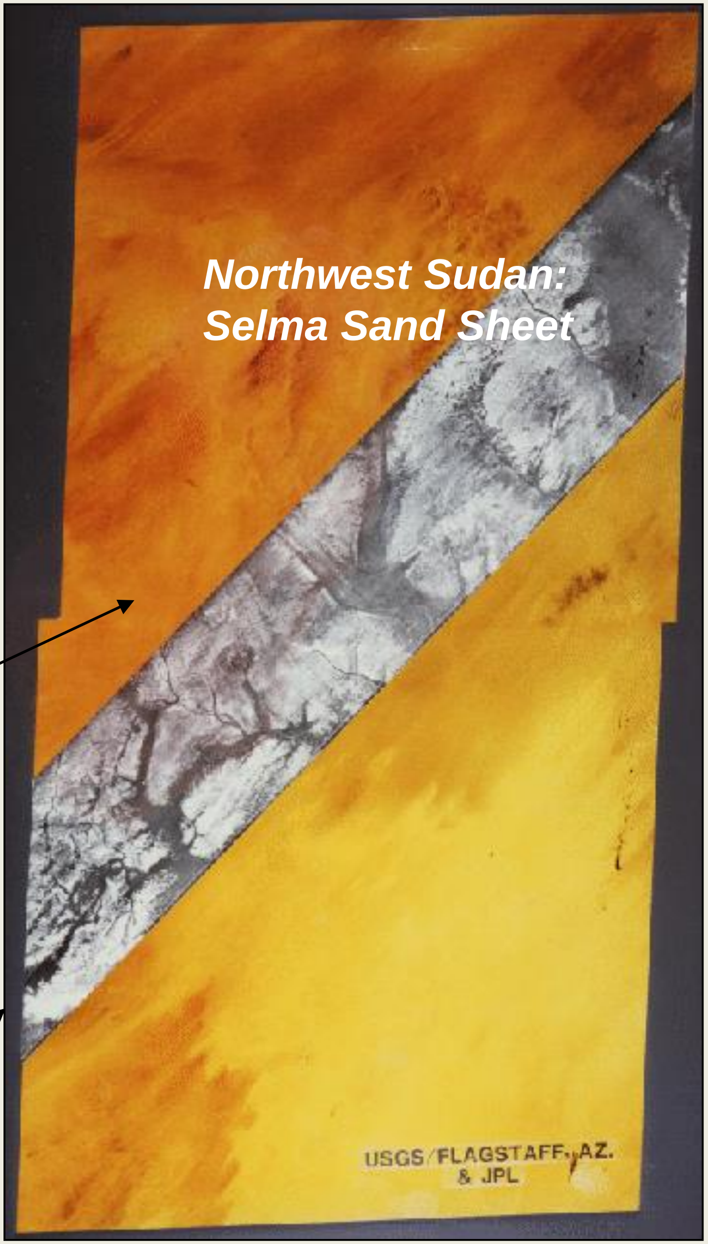
SAR: beyond visible

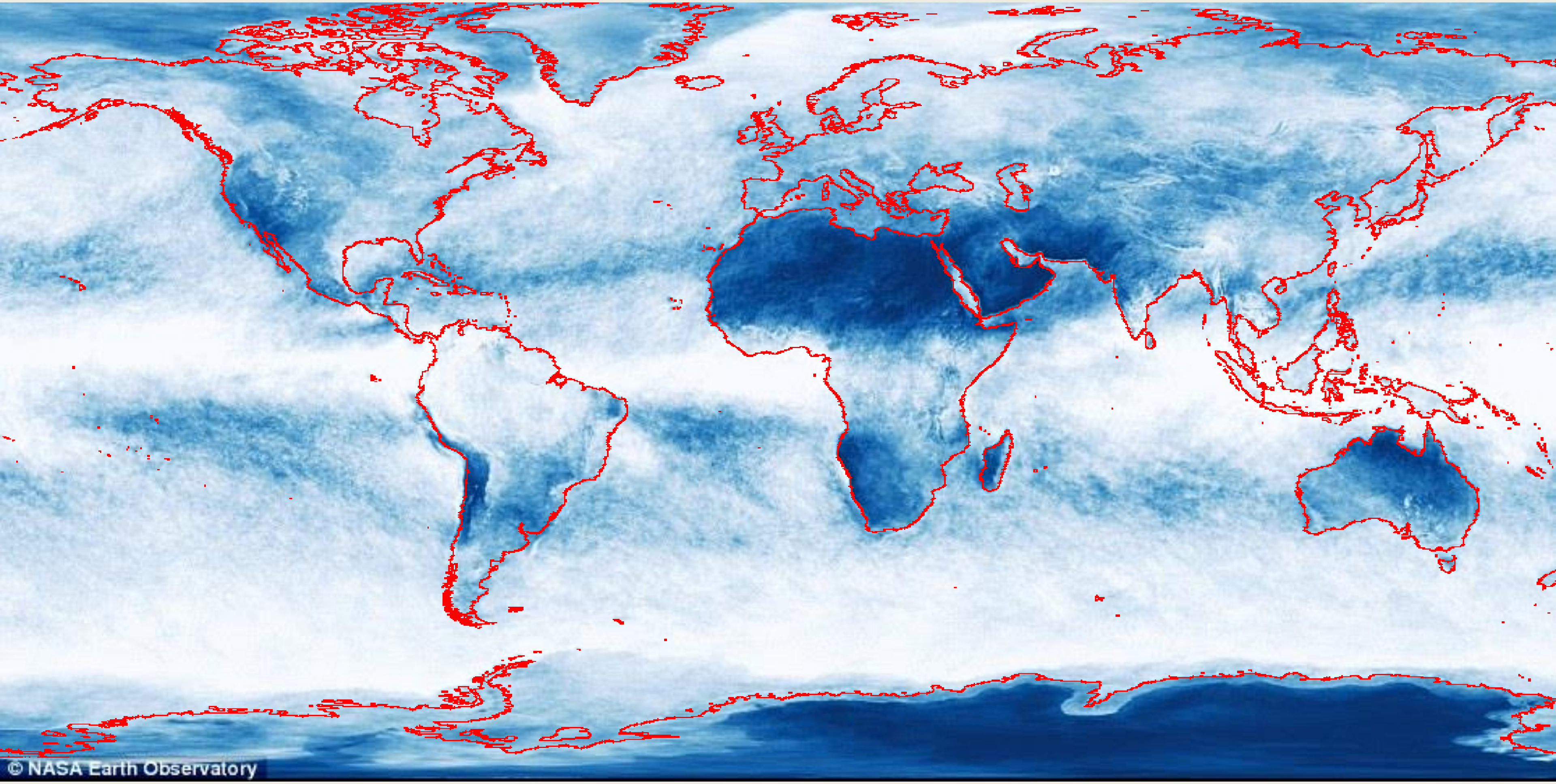
- SAR at microwave wavelengths interact with the *geometric* and *electrical* properties of surfaces
- SAR observations allow us to experience the Earth in a fundamentally different light, day or night
- SAR at typical wavelengths can penetrate cloud cover



Optical

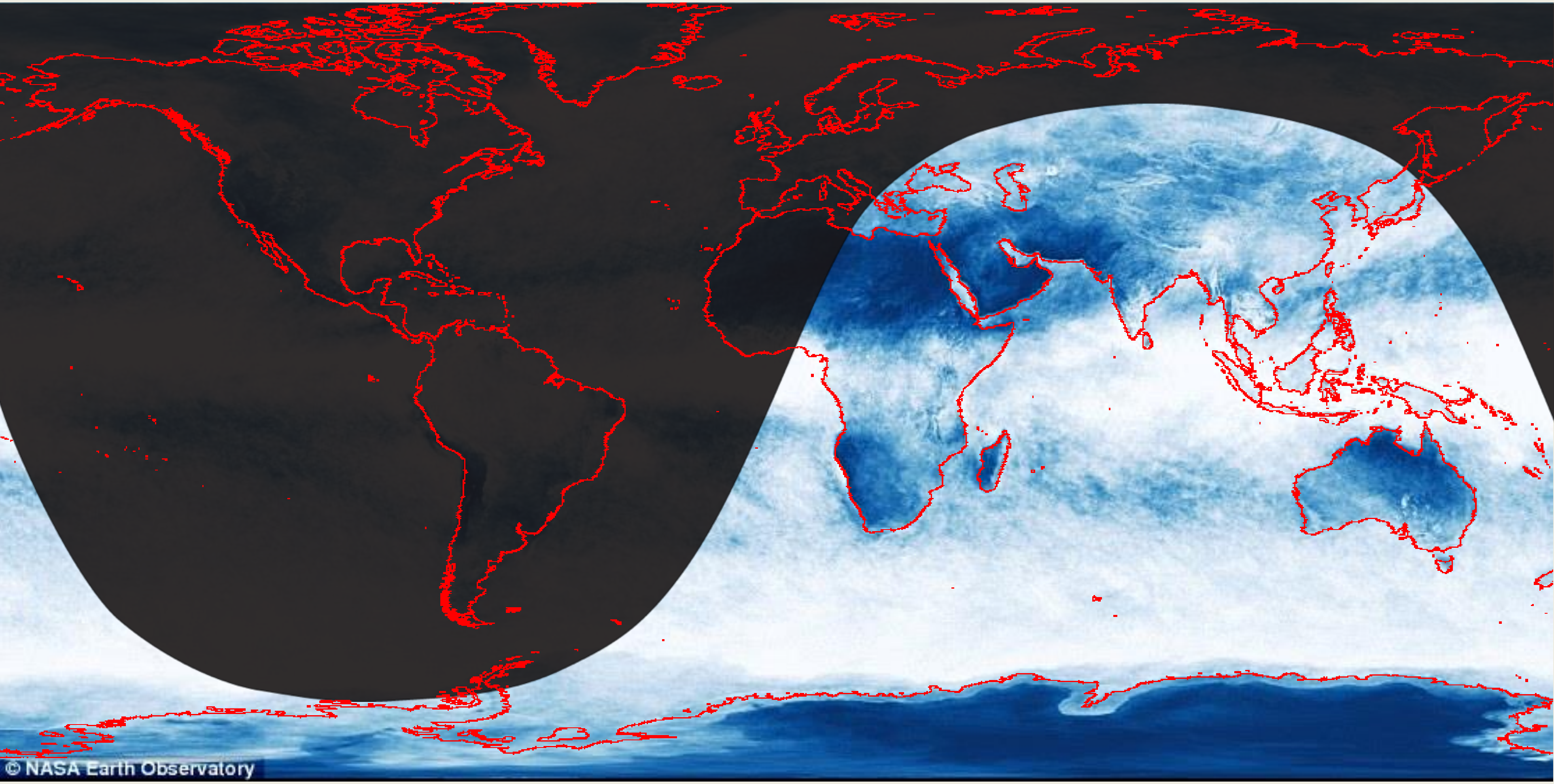
L-band (24 cm) SAR
Shuttle Imaging Radar-A

Earth is Mostly Cloudy



Average cloudiness over Earth in April 2015 seen from Aqua Satellite. At any given time, around 70% of the Earth is covered by clouds.

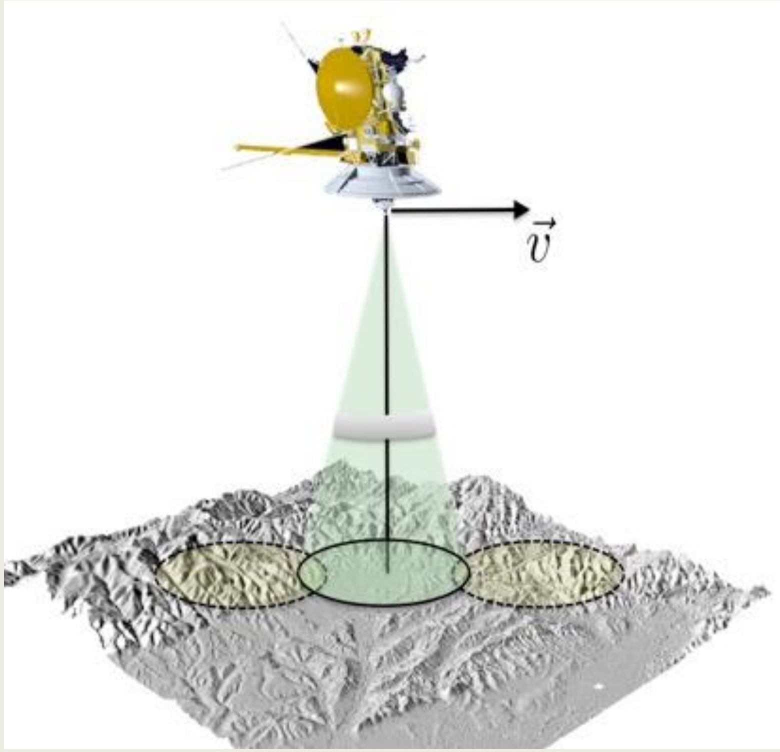
And Half Dark



At any given time, 50% of the earth is dark.

Radar Remote Sensors

- **Altimeters**
  - height of a surface
- **Sounders/Profilers**
  - volume composition and structure
- **Scatterometers**
  - surface composition and roughness
- **Synthetic Aperture Radar (SAR)**
  - surface composition and roughness imagery
- **Polarimeters**
  - improves surface or volume structure information
- **Interferometers**
  - topography and topographic change



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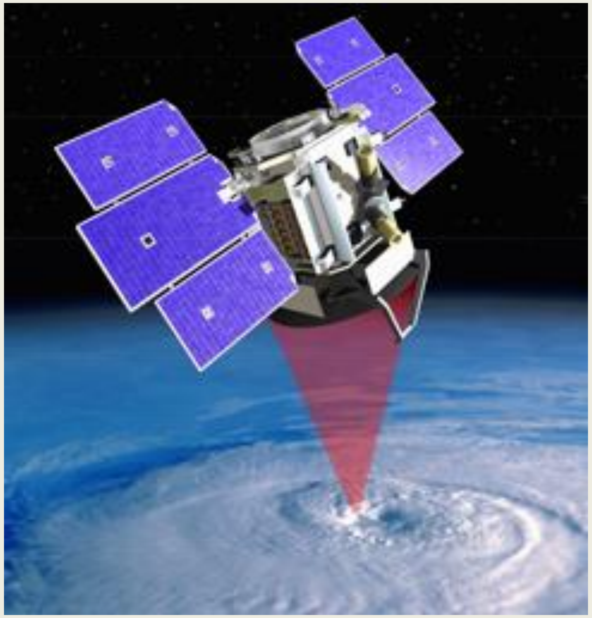

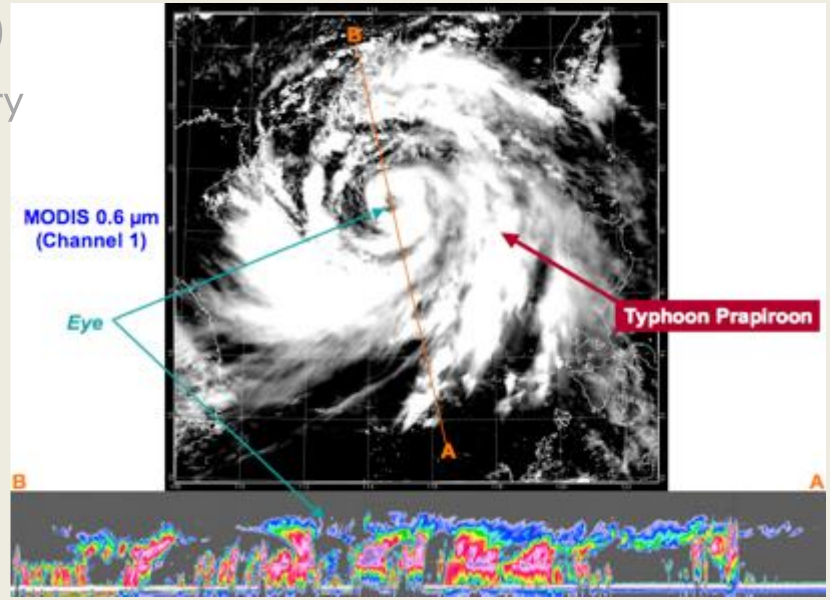

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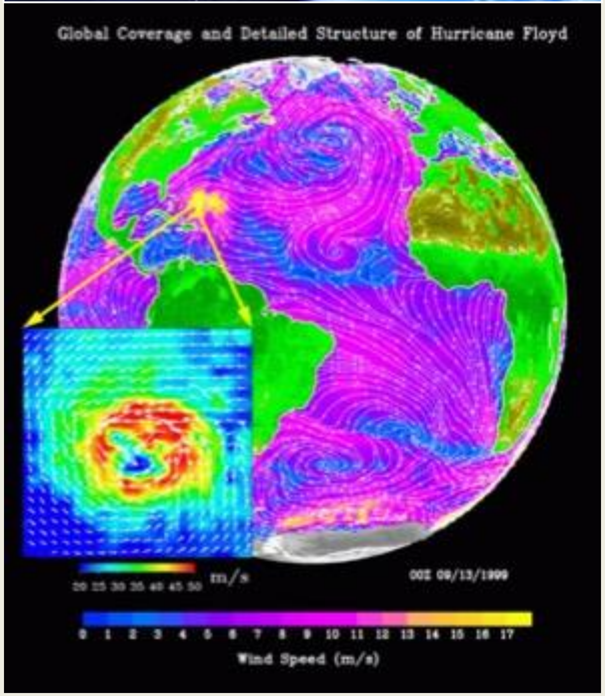

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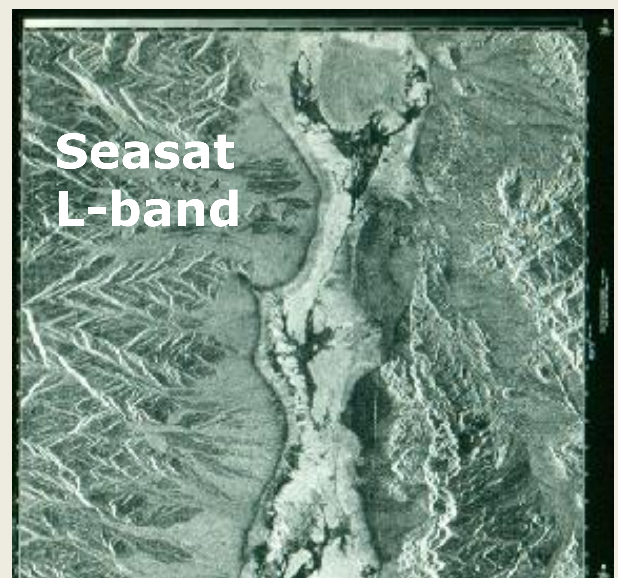

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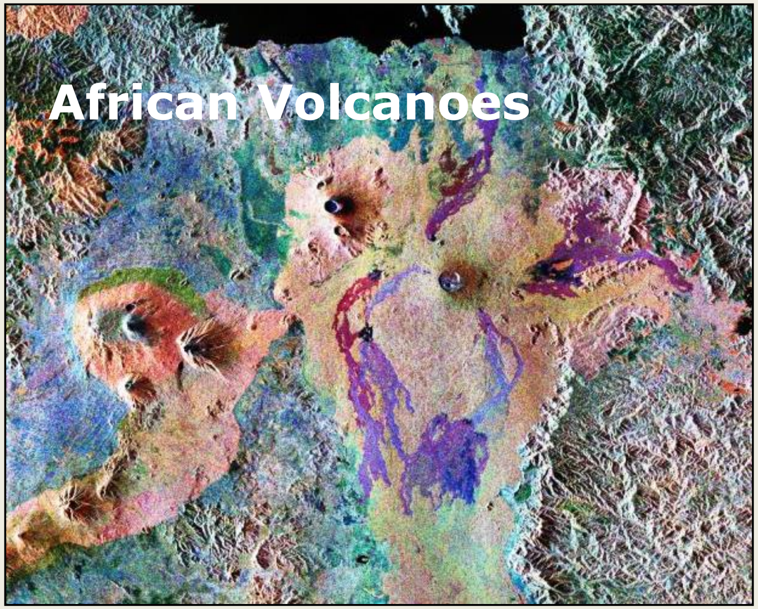

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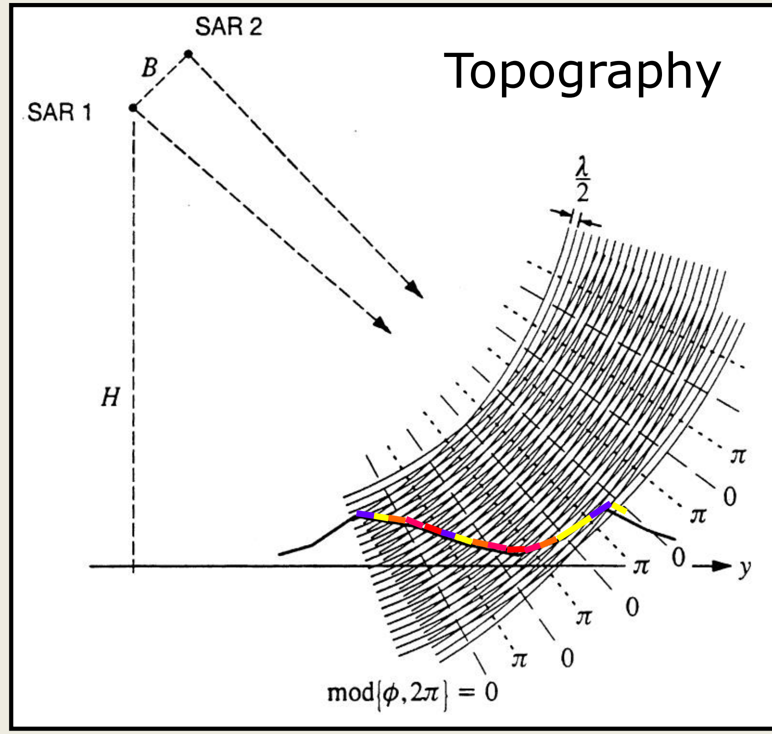
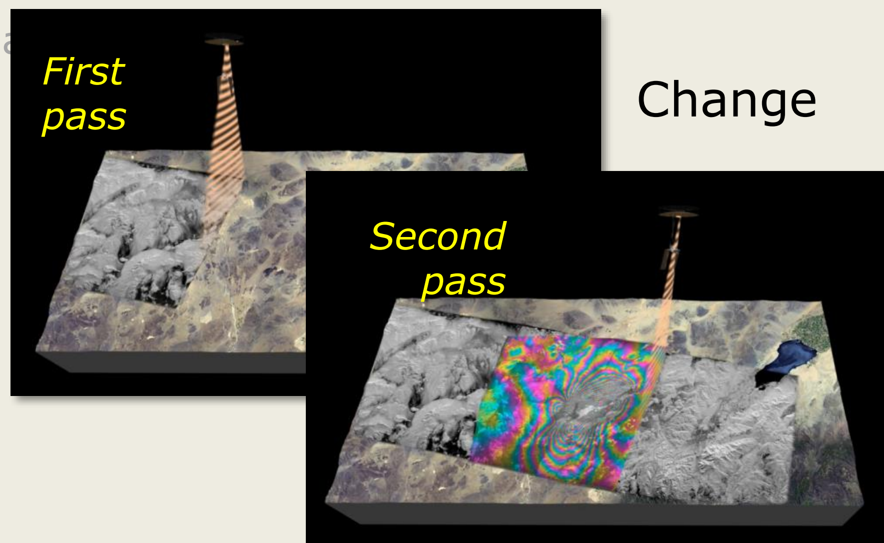
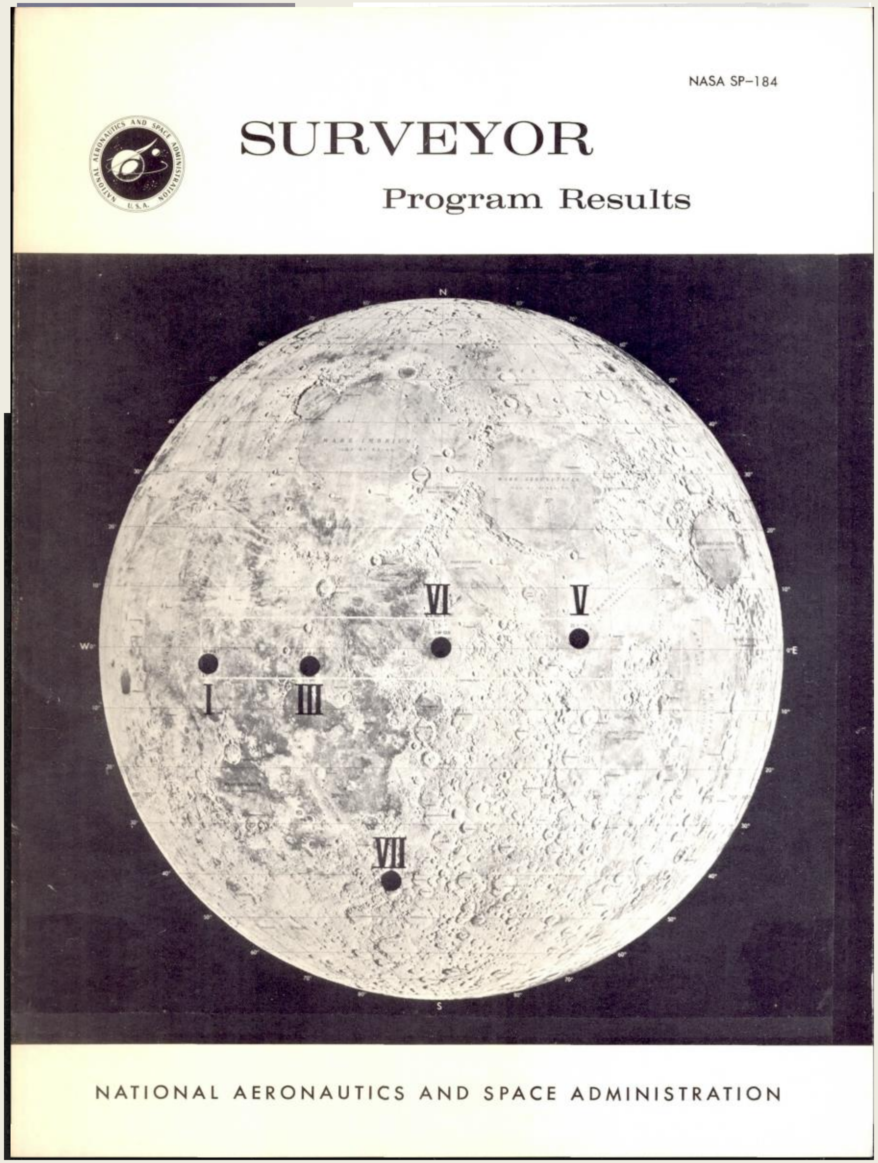




Change

Early JPL Radar Developments

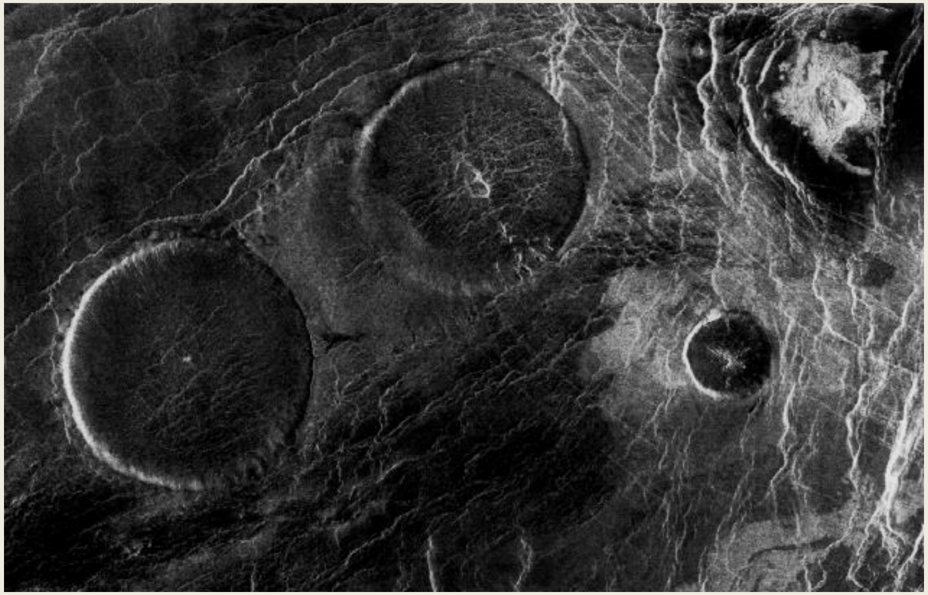



1970- LHH Airborne Radar Image of Death Valley

Magellan Radar To Venus

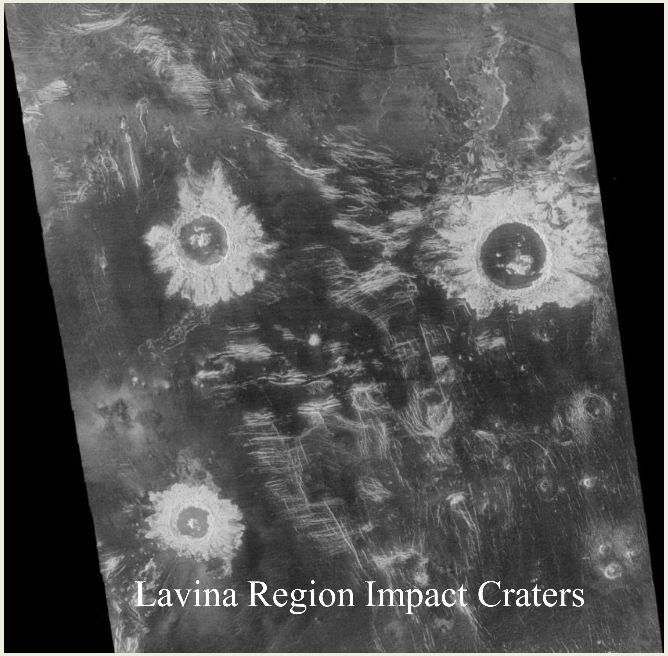
Magellan radar mapped 98% of the surface of Venus with an S-Band (12 cm) radar.

Impact Crater

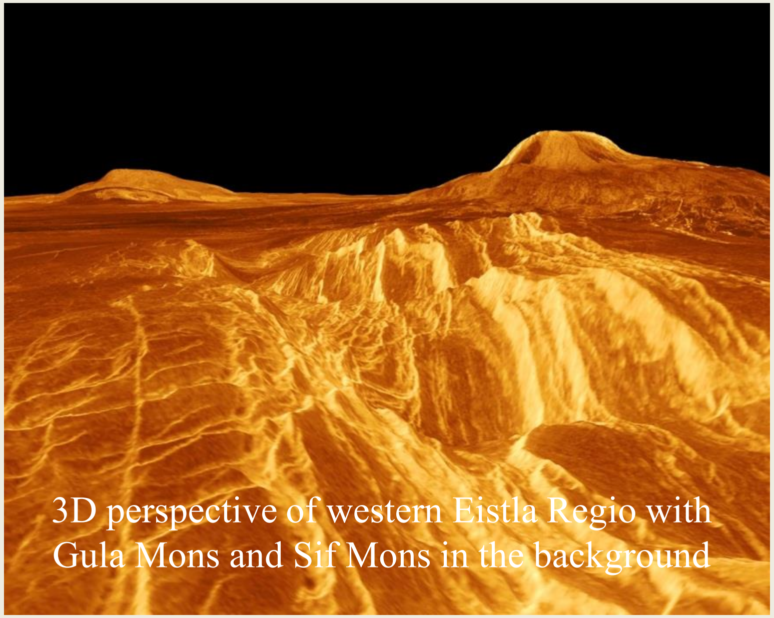


Pancake Volcanoes

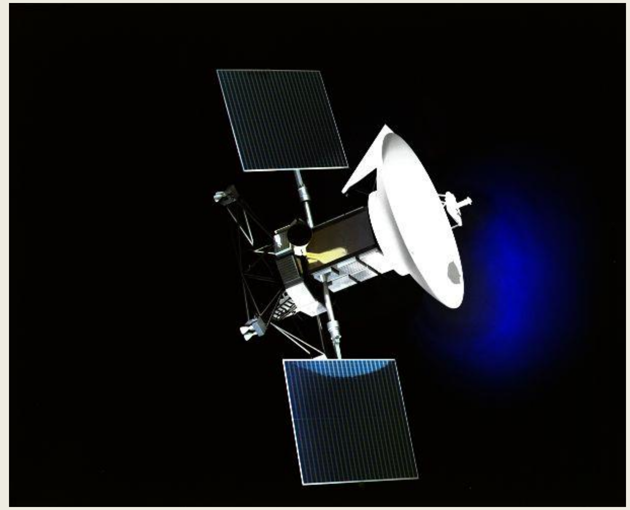
Planetary Radars: Magellan

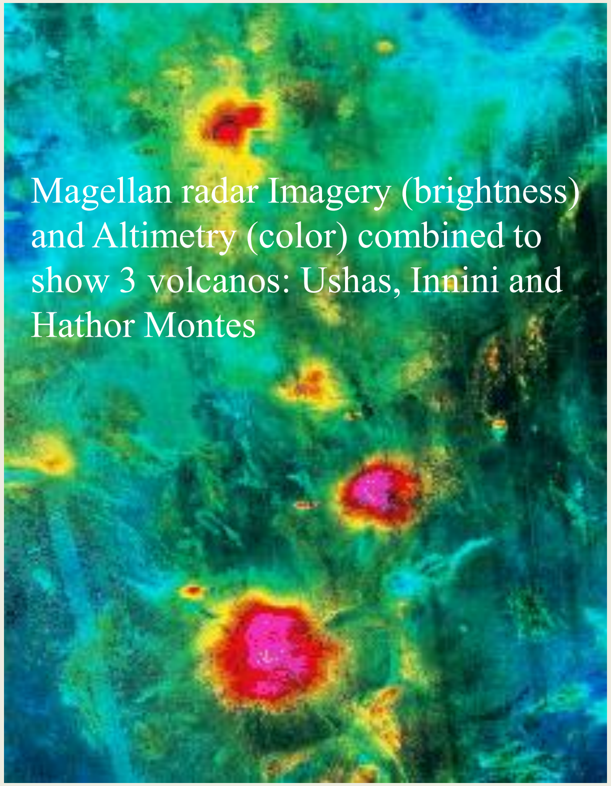


Lavina Region Impact Craters



3D perspective of western Eistla Regio with Gula Mons and Sif Mons in the background



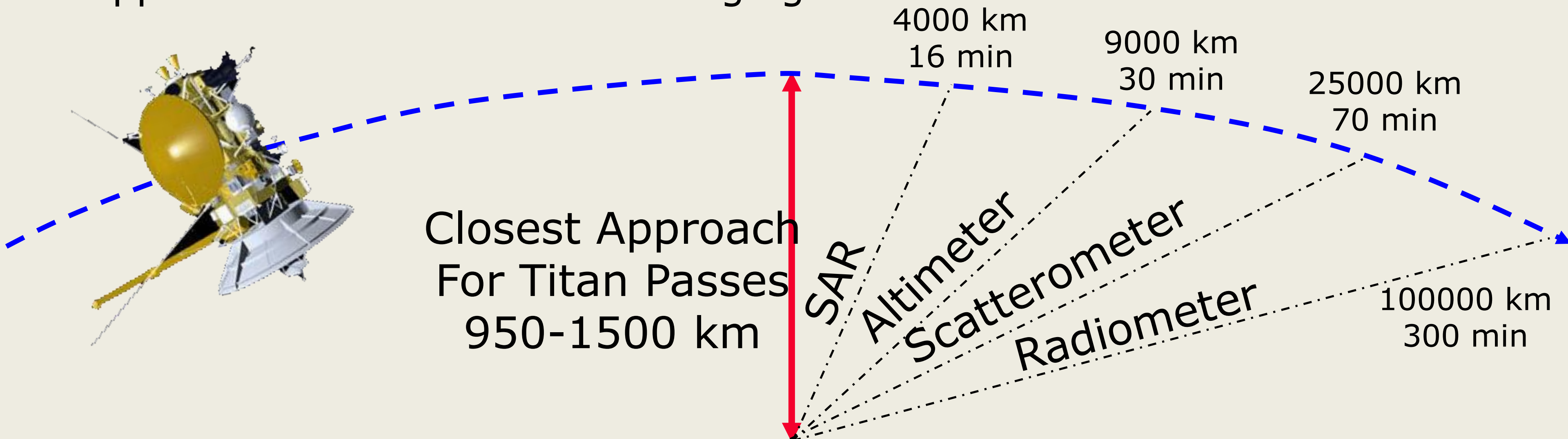


Magellan radar Imagery (brightness) and Altimetry (color) combined to show 3 volcanos: Ushas, Innini and Hathor Montes

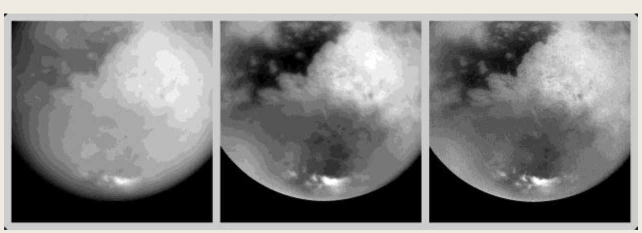
Global view of Venus with Ovda Region in center

Titan Observation Geometry

SAR imaging takes place from around ±16 minutes from closest approach with altitude Titan ranging from 4000 km to 1000 km.



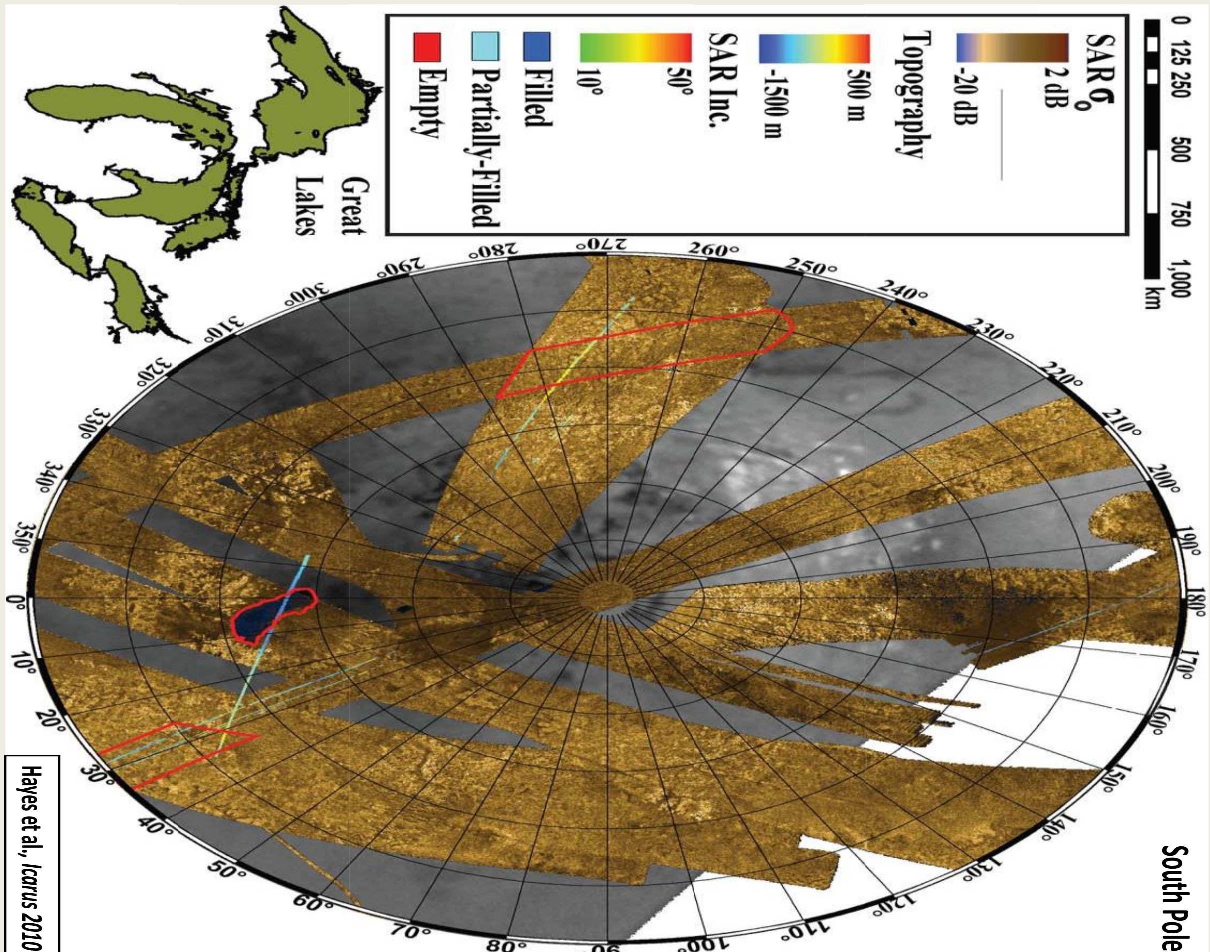
Infrared Images of Titan



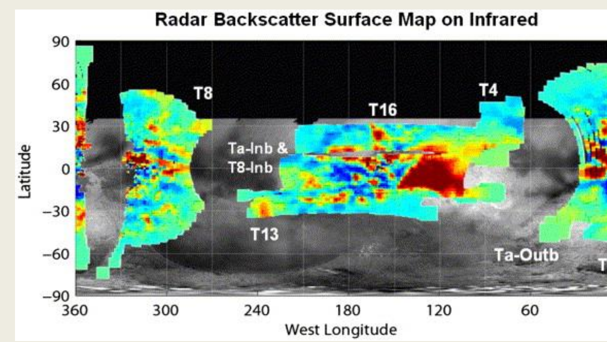
Titan:

- Only moon with significant atmosphere (N_2)
- Surface Temperature: 85°K
- Radius: 2575 km
- Surface: Methane and other hydrocarbons ices and liquids

Cassini Radar Results



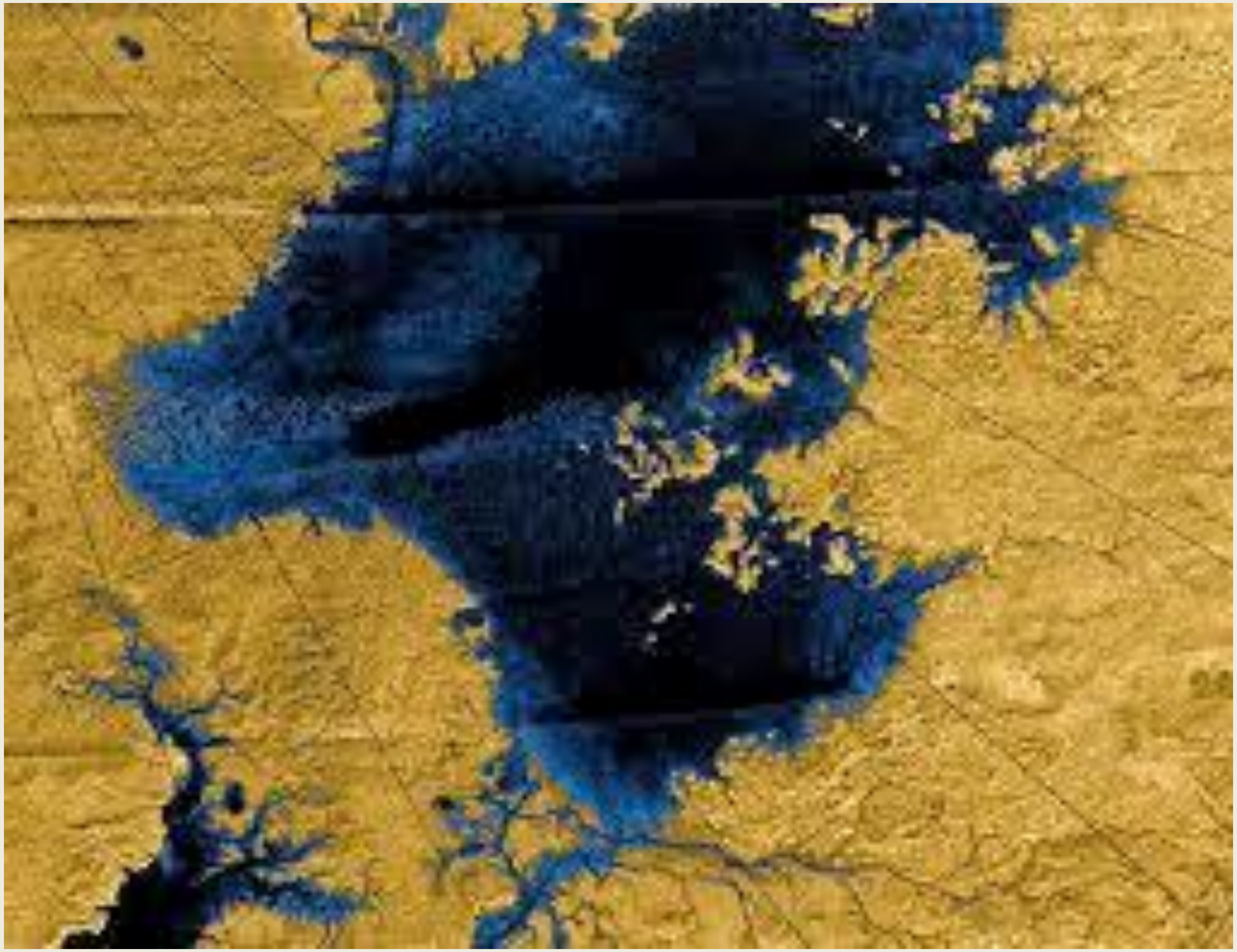
(Courtesy S. Hensley)



Wye et al. (Icarus, 2007)

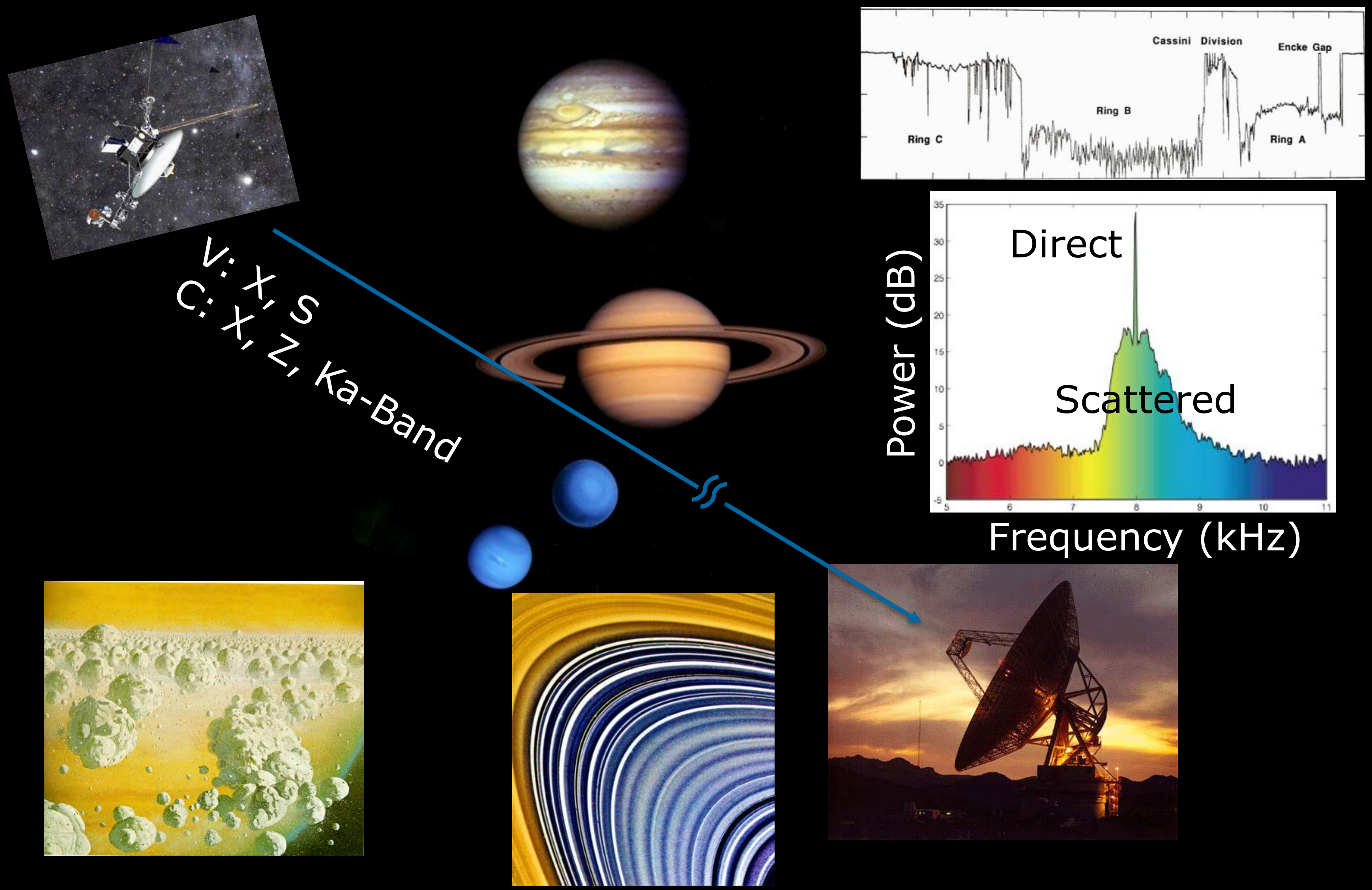
Cassini Radar

The Ku-band (2.5 cm) Cassini radar map the only other known liquid bodies, hydrocarbon lakes, on the Saturn moon Titan.

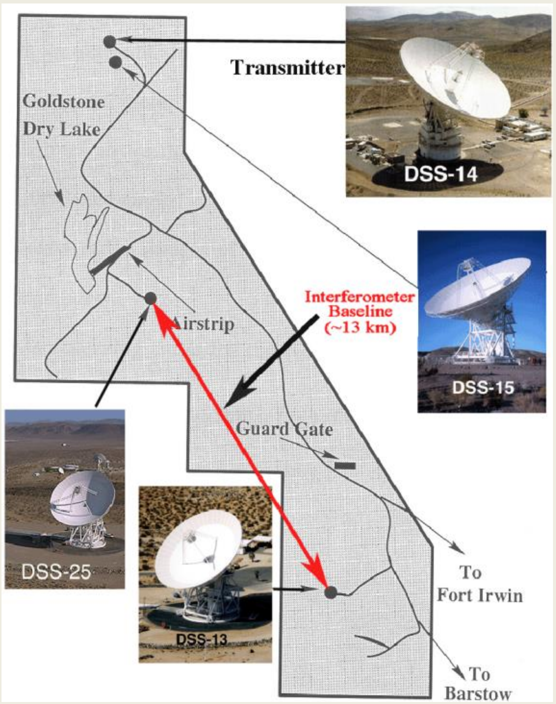


Ligeia Mare – Roughly the size of Lake Superior

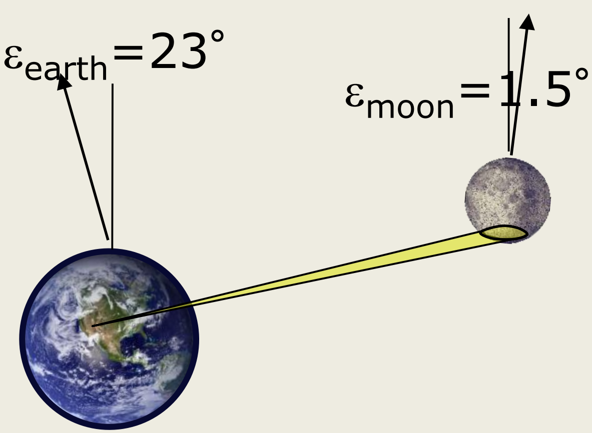
Voyager/Cassini Radio Occultation – Bistatic CW Radar Remote Sensing

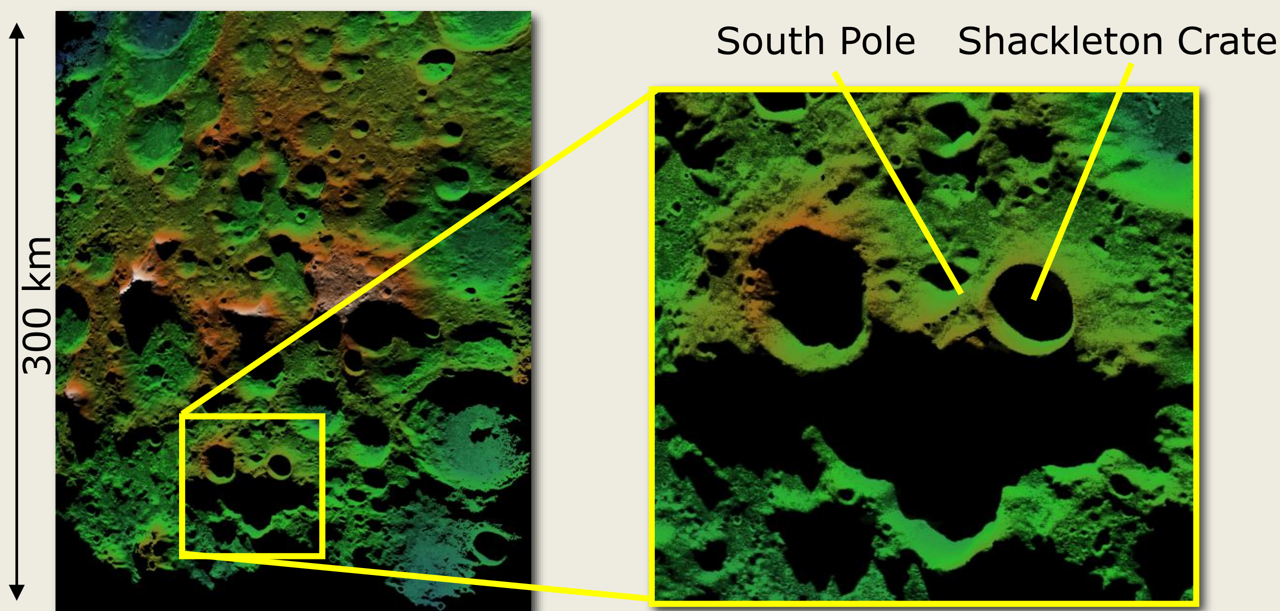


NASA Goldstone Solar System Radar Interferometer – Lunar Topography



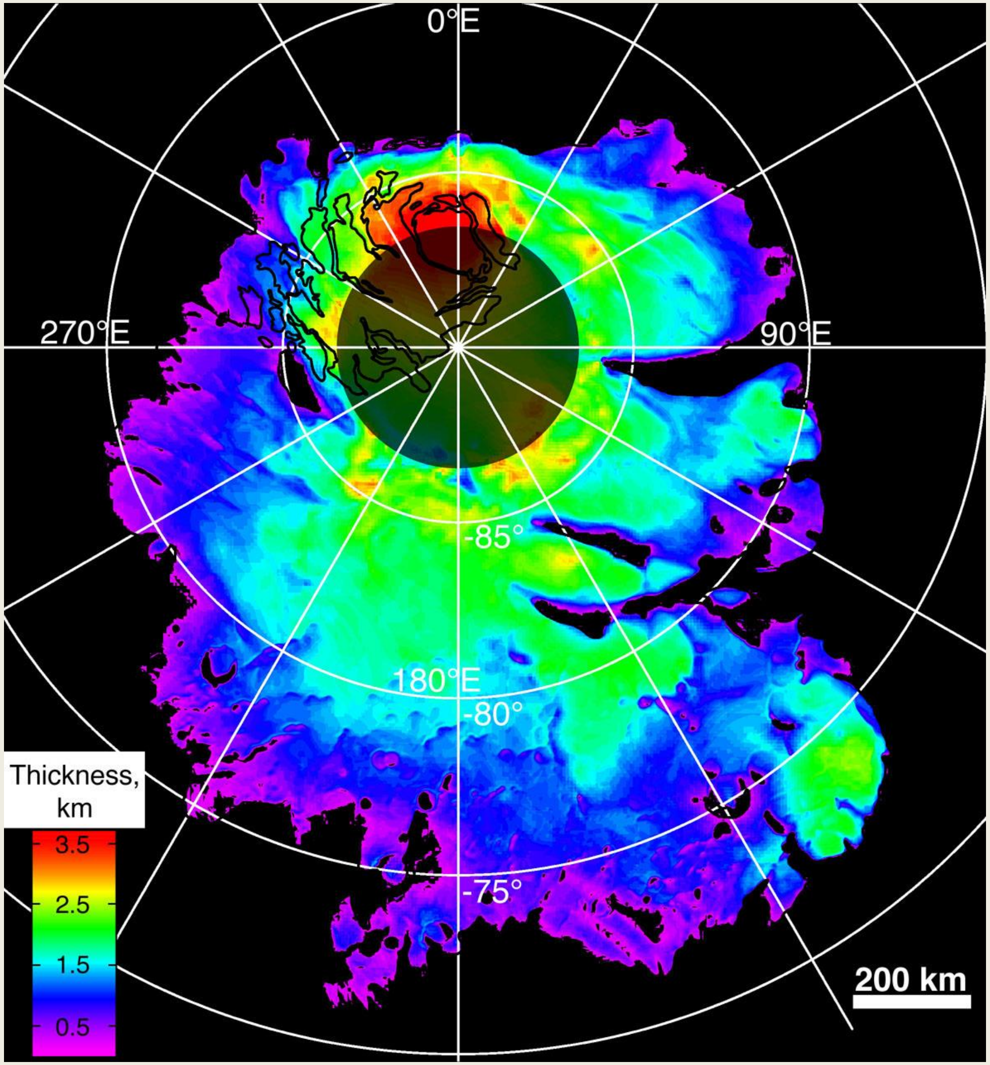
- A unique NASA facility for high-resolution topographic mapping
  - One transmitting, multiple receiving antennas for interferometry
  - 500 kW X-band transmitter
  - Very sensitive maser receiver
- Finest resolution and accuracy topographic maps of the moon available in 2006
  - 150 m resolution, 5 m vertical accuracy

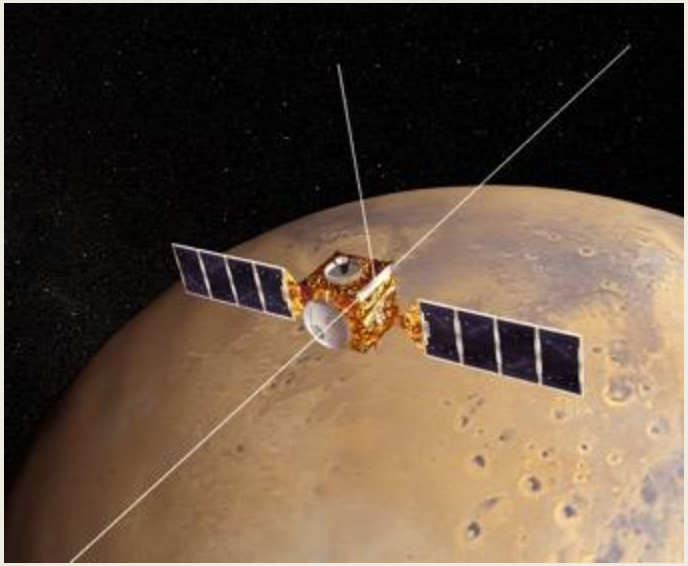




Courtesy GSSR Team

Mars South Polar Cap Thickness from MARSIS

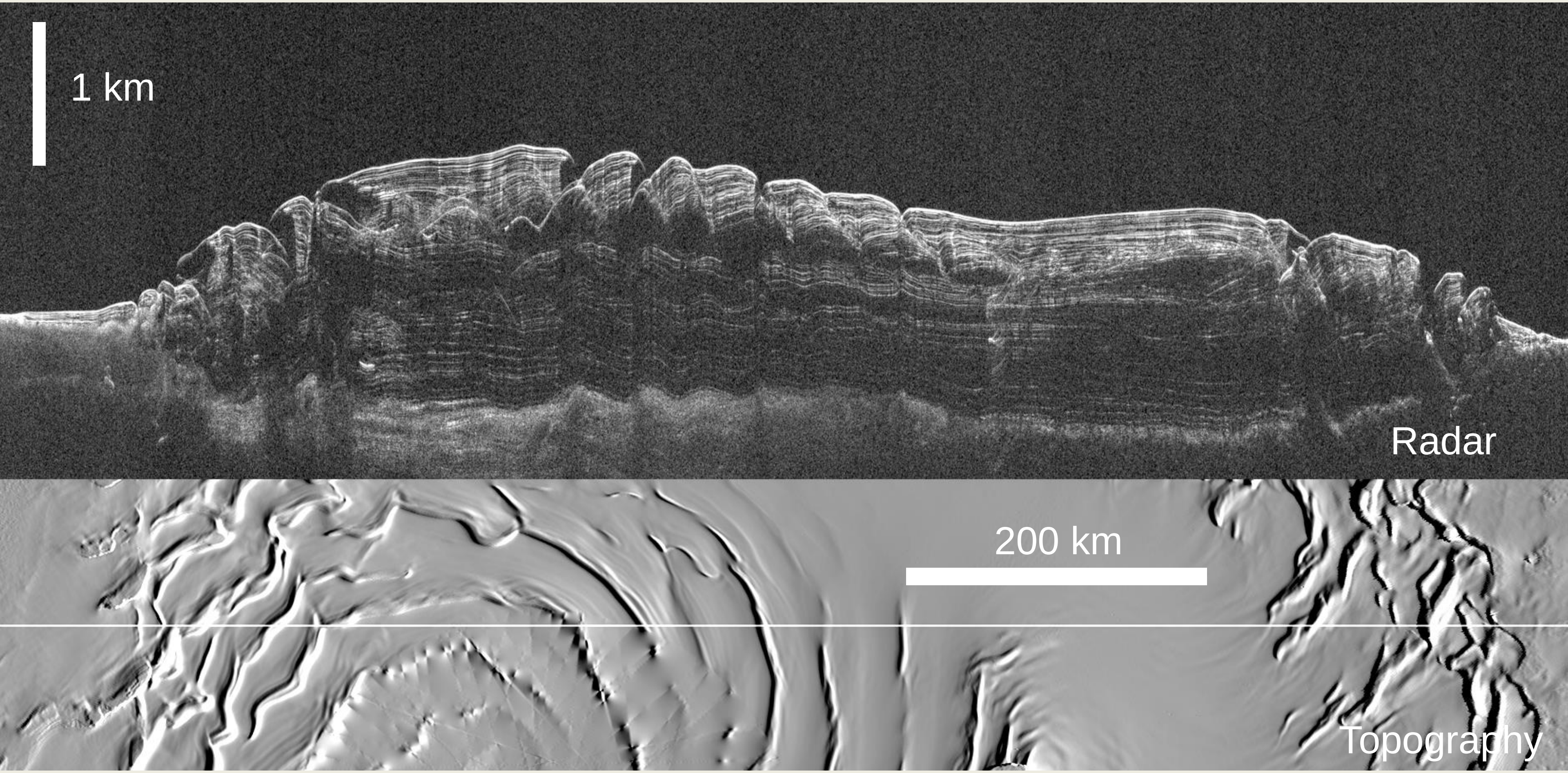




HF with wide relative bandwidth

Probes subsurface and ionosphere

SHARAD Slice Through Mars North Polar Cap



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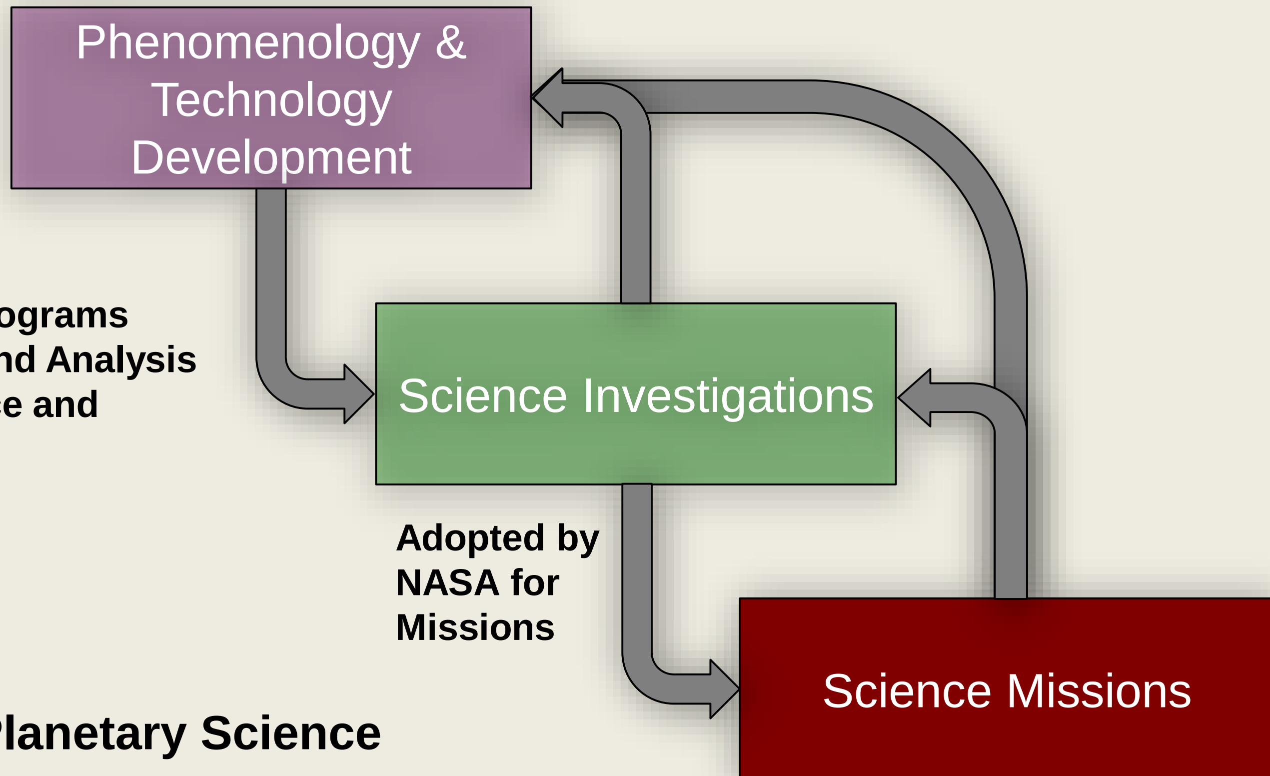
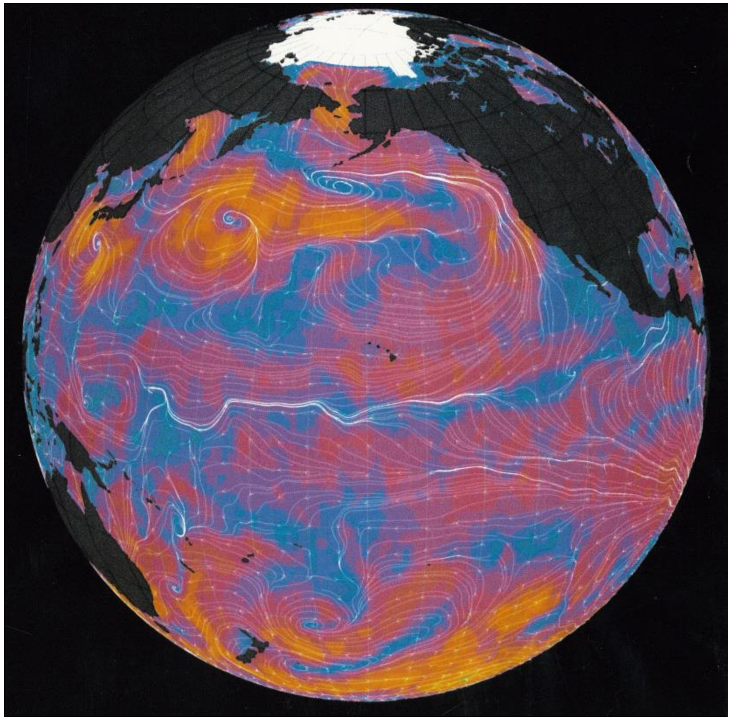
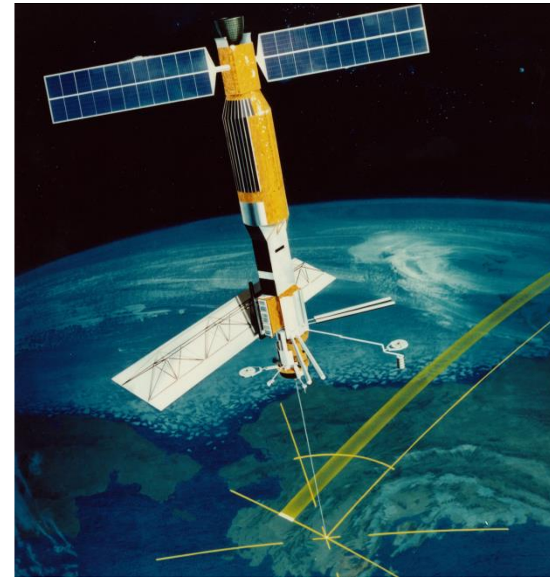
NASA Science-Driven Research and Missions Foster New Uses for Radar in Remote Sensing

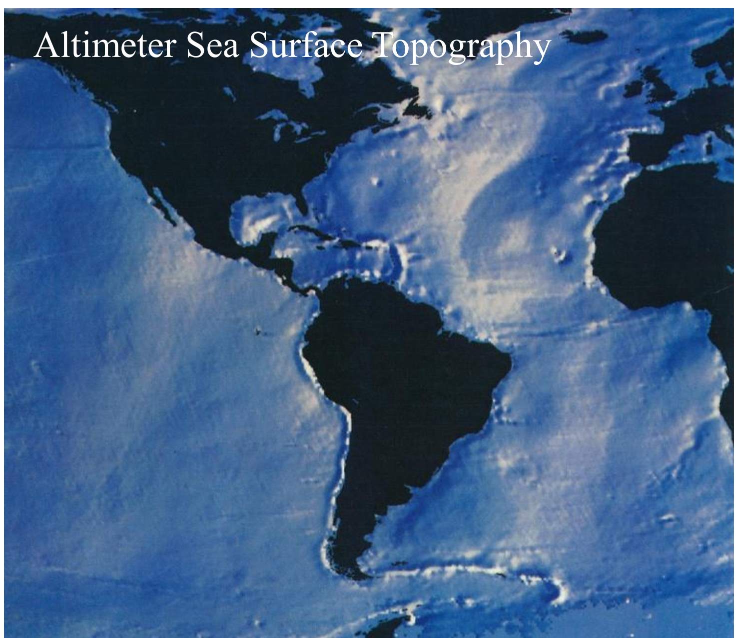


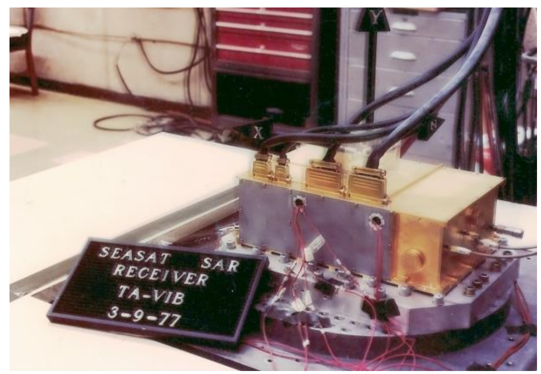
- Robust Airborne programs
- Robust Research and Analysis Programs in Science and Technology

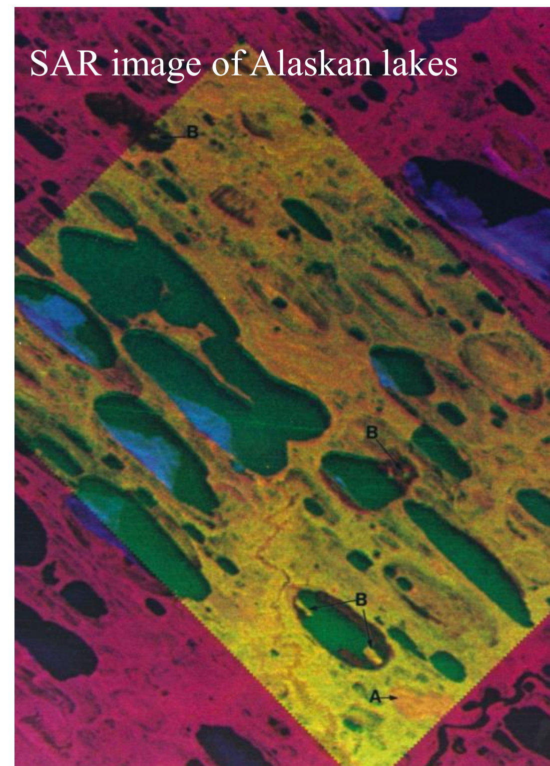
- **NASA Earth and Planetary Science**
  - Global reach
  - Wide-area coverage
  - High science performance
  - Enabling technology for science, not for its own sake



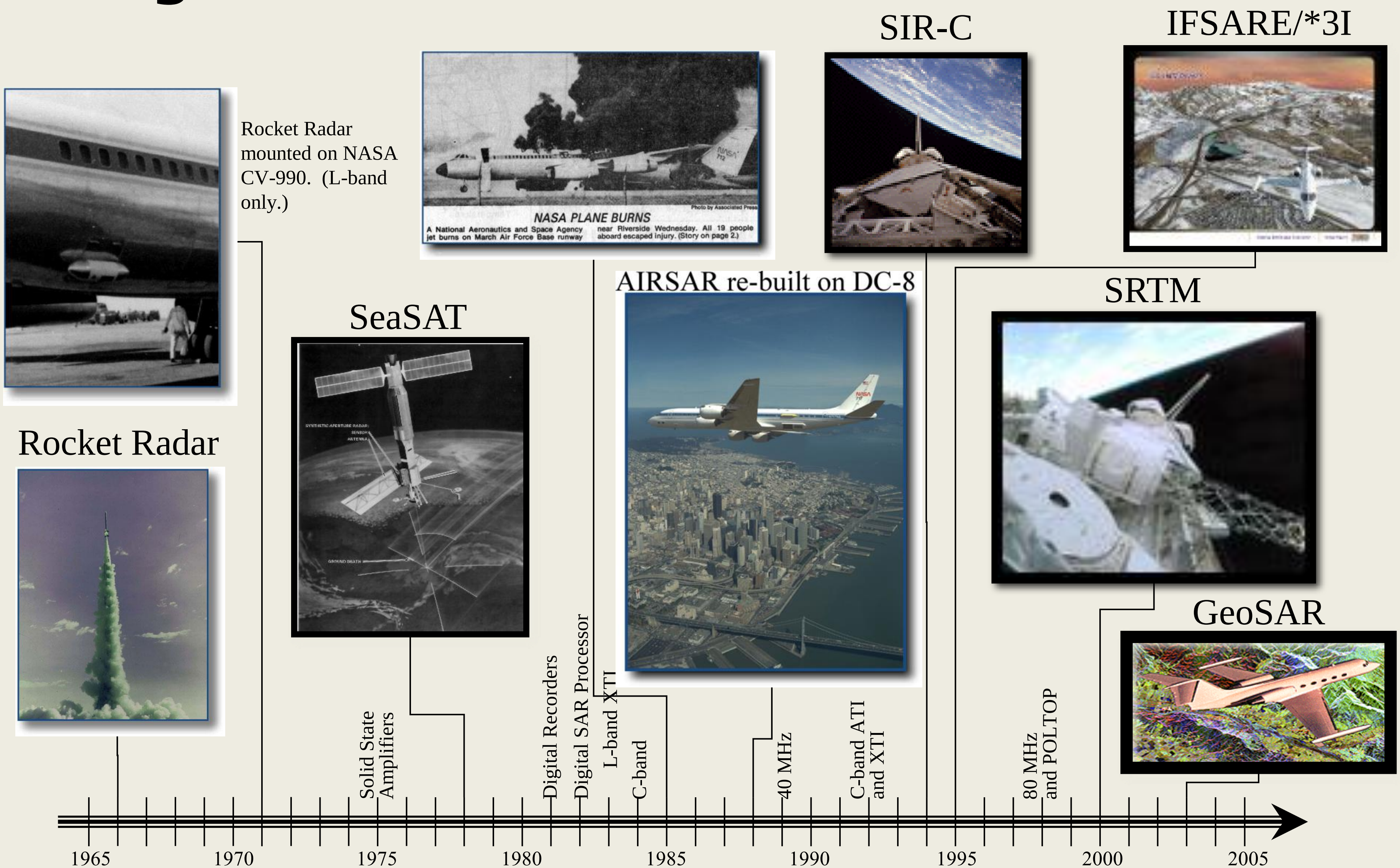



Altimeter Sea Surface Topography




SAR image of Alaskan lakes

Coupled Airborne and Spaceborne SAR Programs



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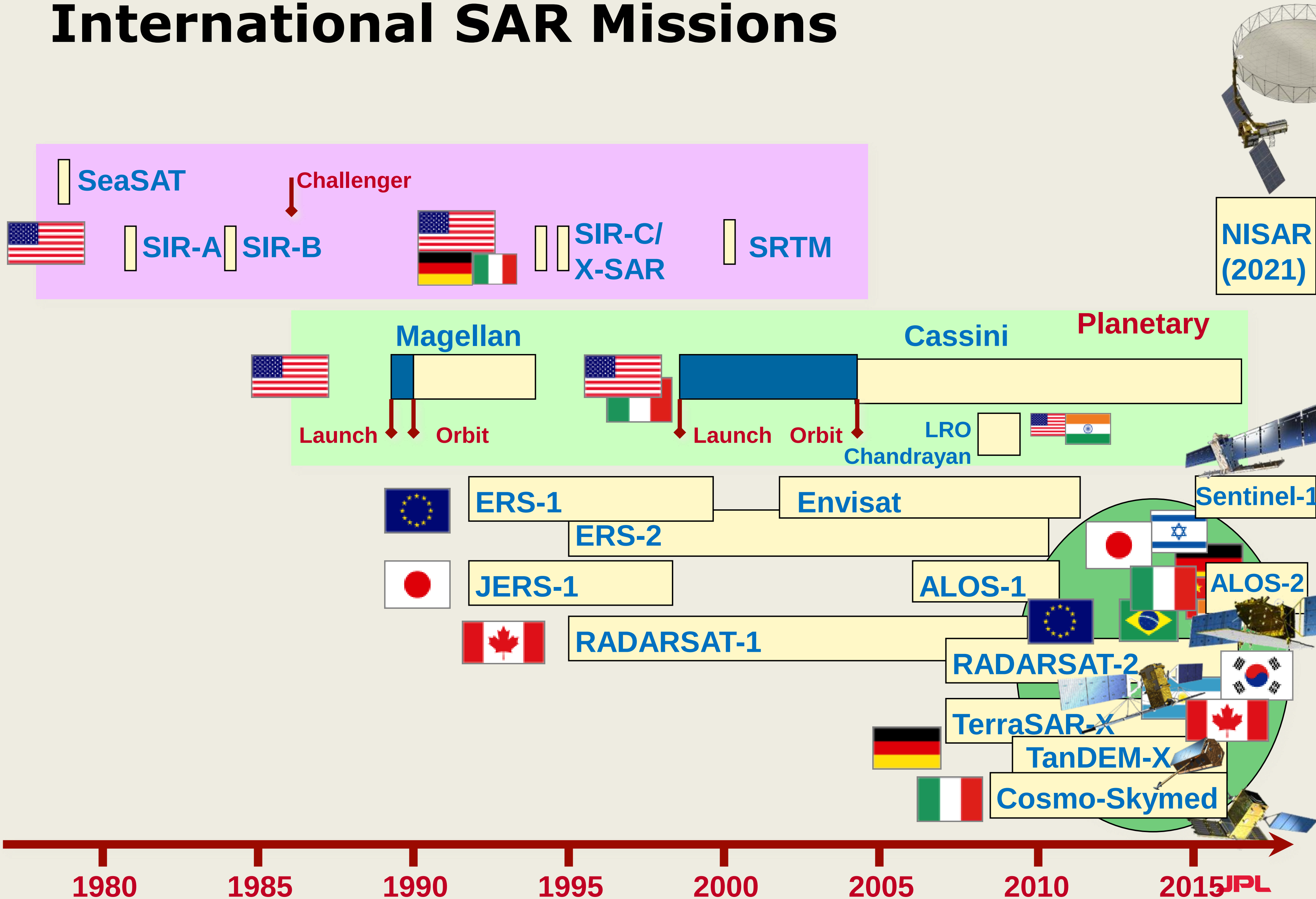
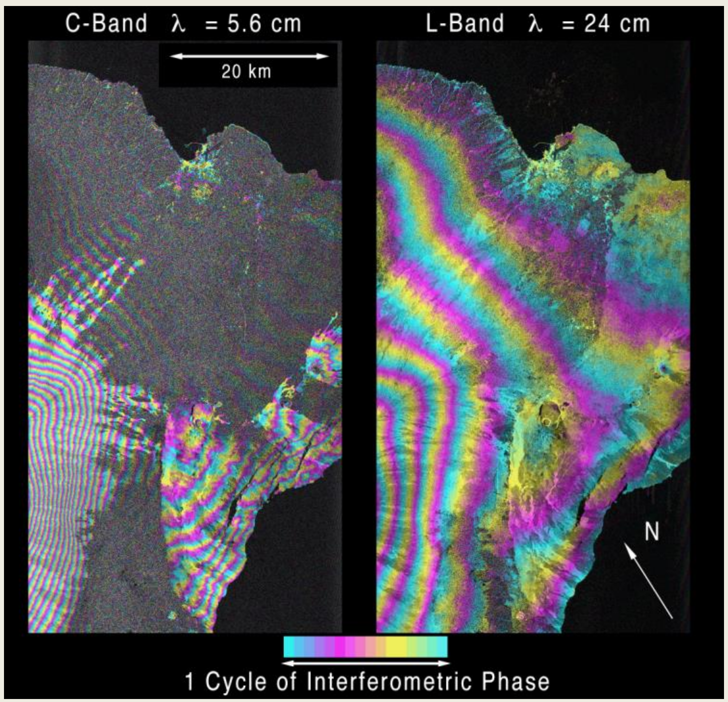
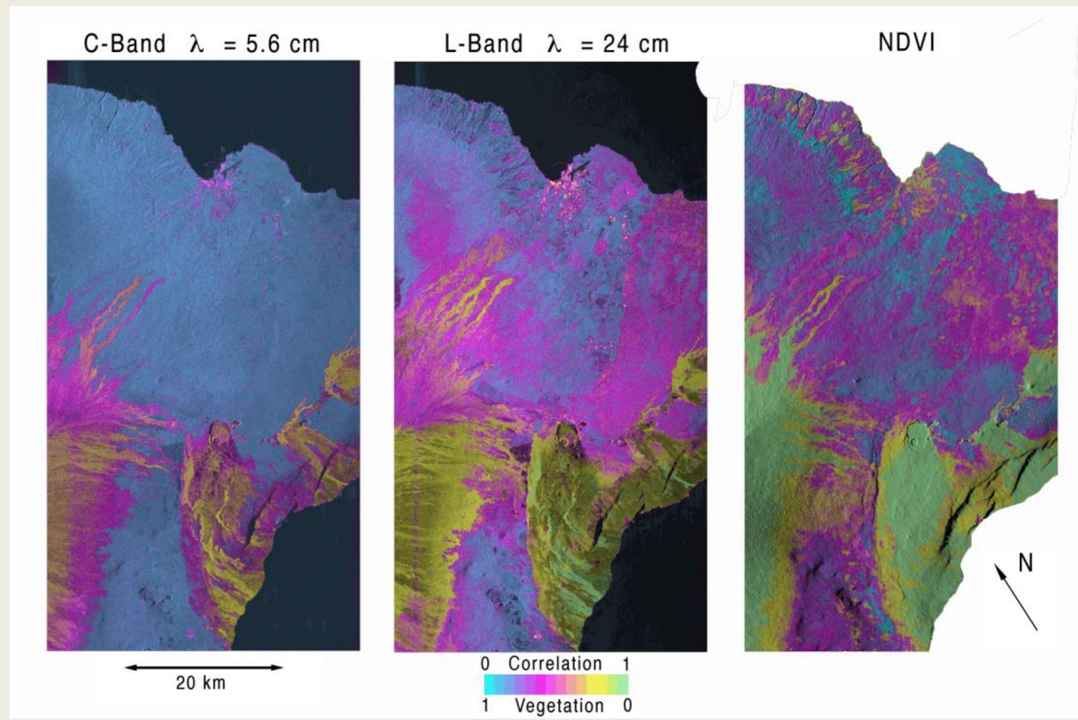
International SAR Missions



Coherent Change Detection
SIR-C L and C-band Interferometry

6 month time separated observations to form interferograms
Simultaneous C and L band

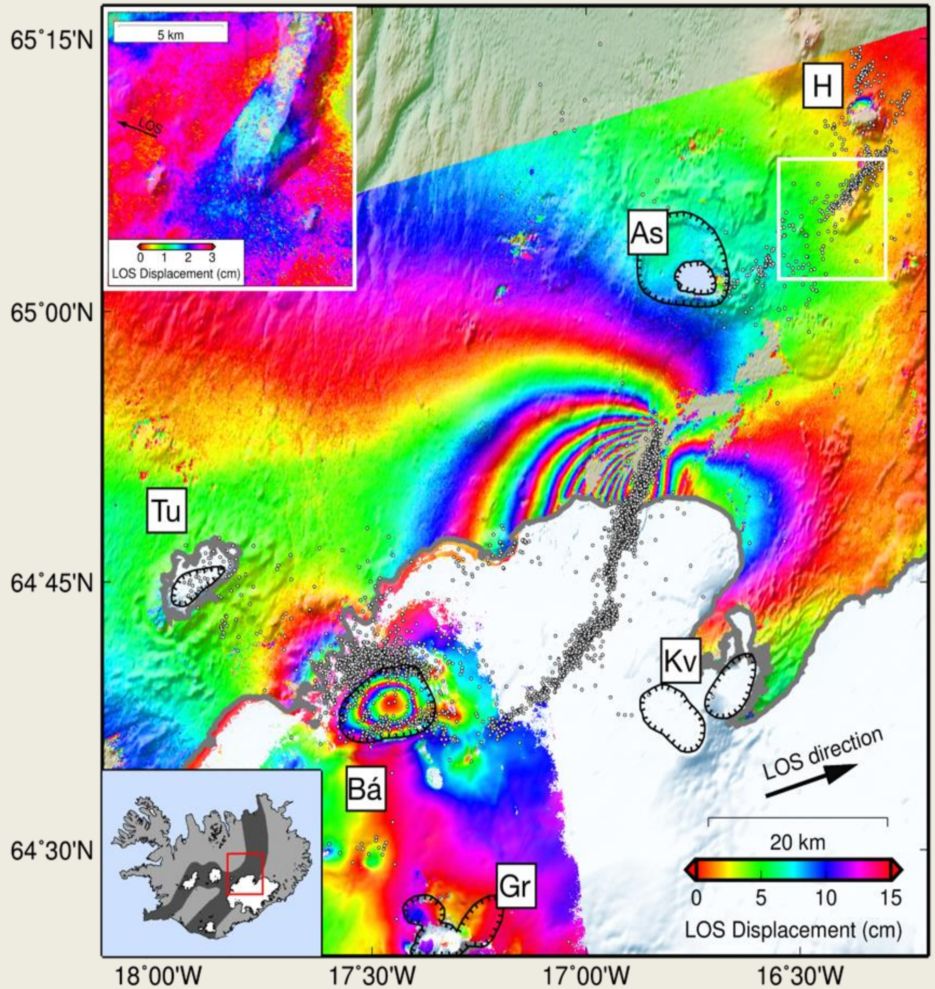




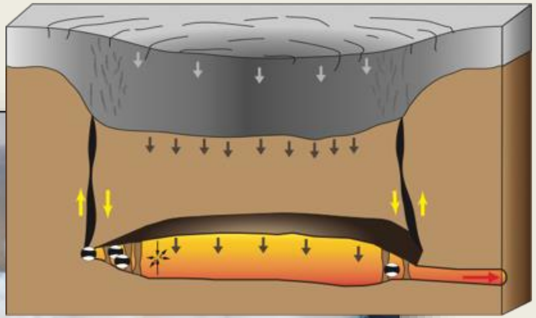
InSAR experiments have shown good correlation at L-band

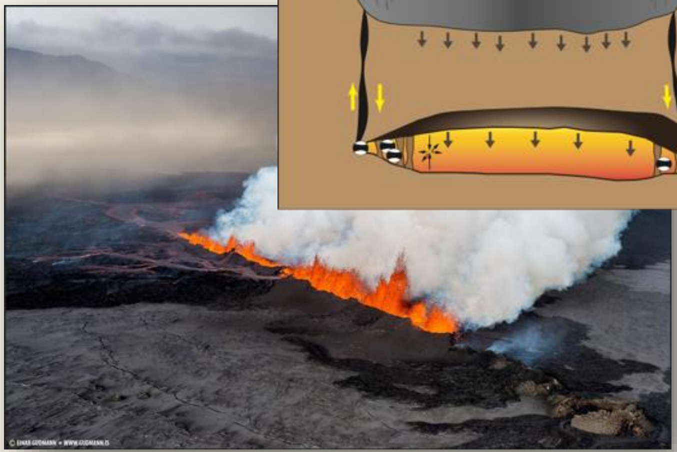
Collapse of Bárdabunga Caldera (Iceland) & associated plate boundary rifting

Fast Sampling (COSMO-SkyMed 1-day) fills in Radarsat 2 24-day pairs

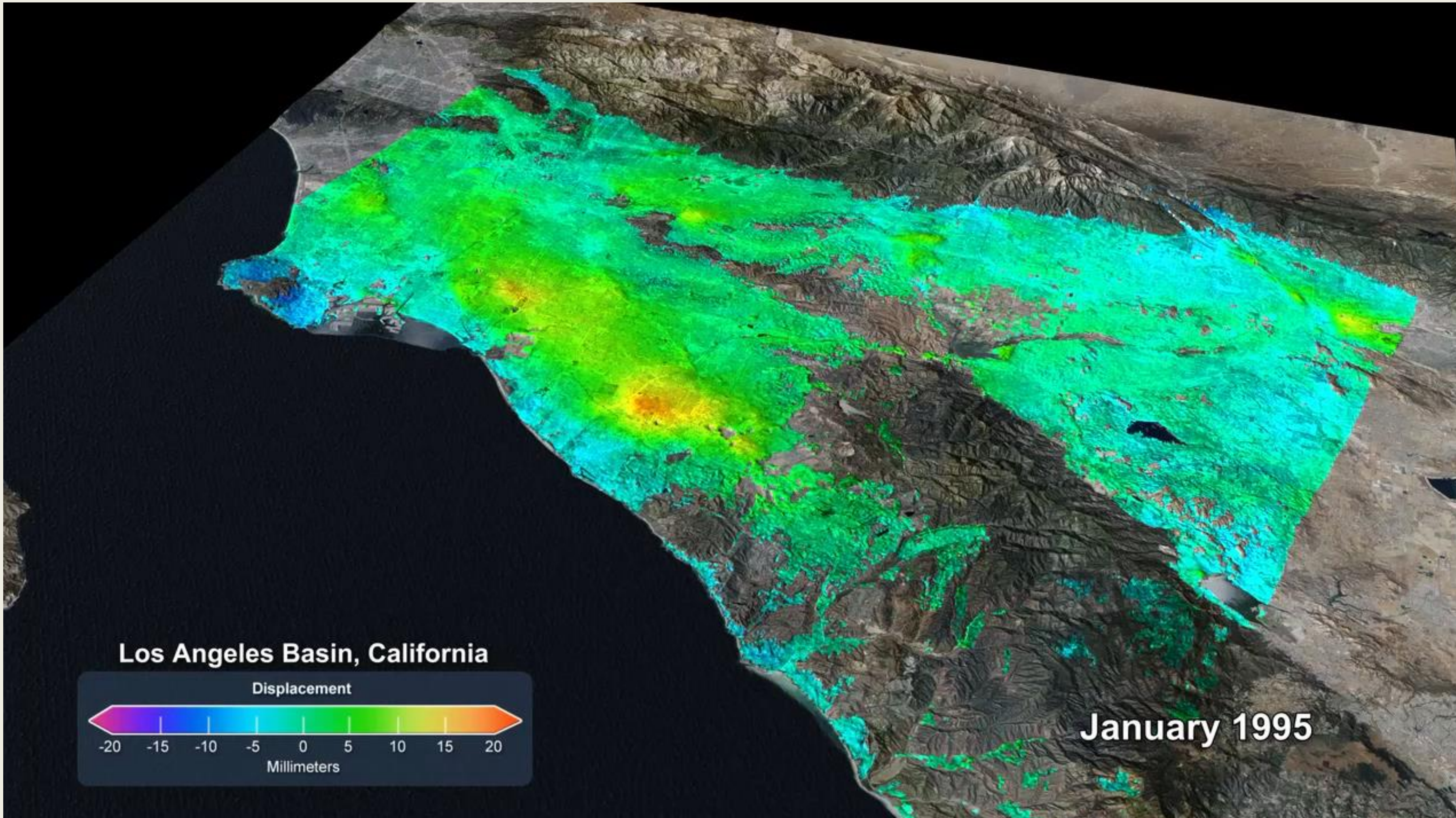


Riel et al., *Geophys. J. Int.*, 2015



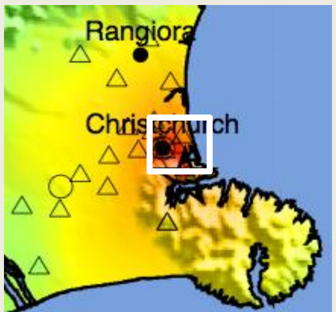


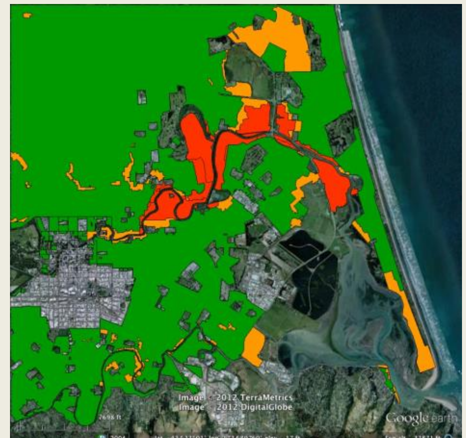
Measuring Aquifer Usage In Los Angeles

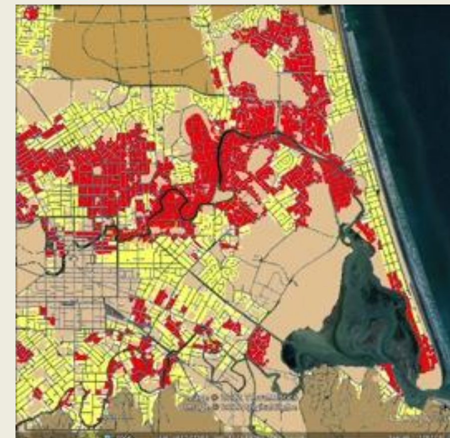


Application to Improve Disaster Response

Damage Proxy Map from radar data







Shakemap released by USGS NEIC

Radar data acquired by ALOS satellite

Official damage map released based on ground observations

Official damage map updated based on ground observations

2011: Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct

M6.3 Christchurch Earthquake

185 people killed > 1000 buildings destroyed Over US $30 billion damage

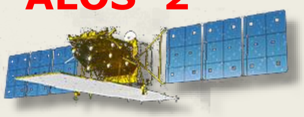
Sang-Ho Yun, JPL

Original ALOS Data © JAXA, METI 2011

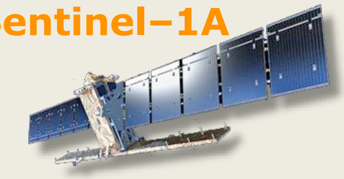
Official damage map provided by the New Zealand Government (http://data.govt.nz)

Synchronized Space-Air-Ground Observations for Historic Floods in Louisiana (August 2016)

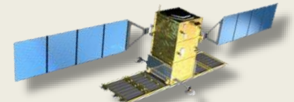
ALOS–2



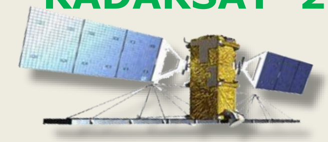
Sentinel–1A

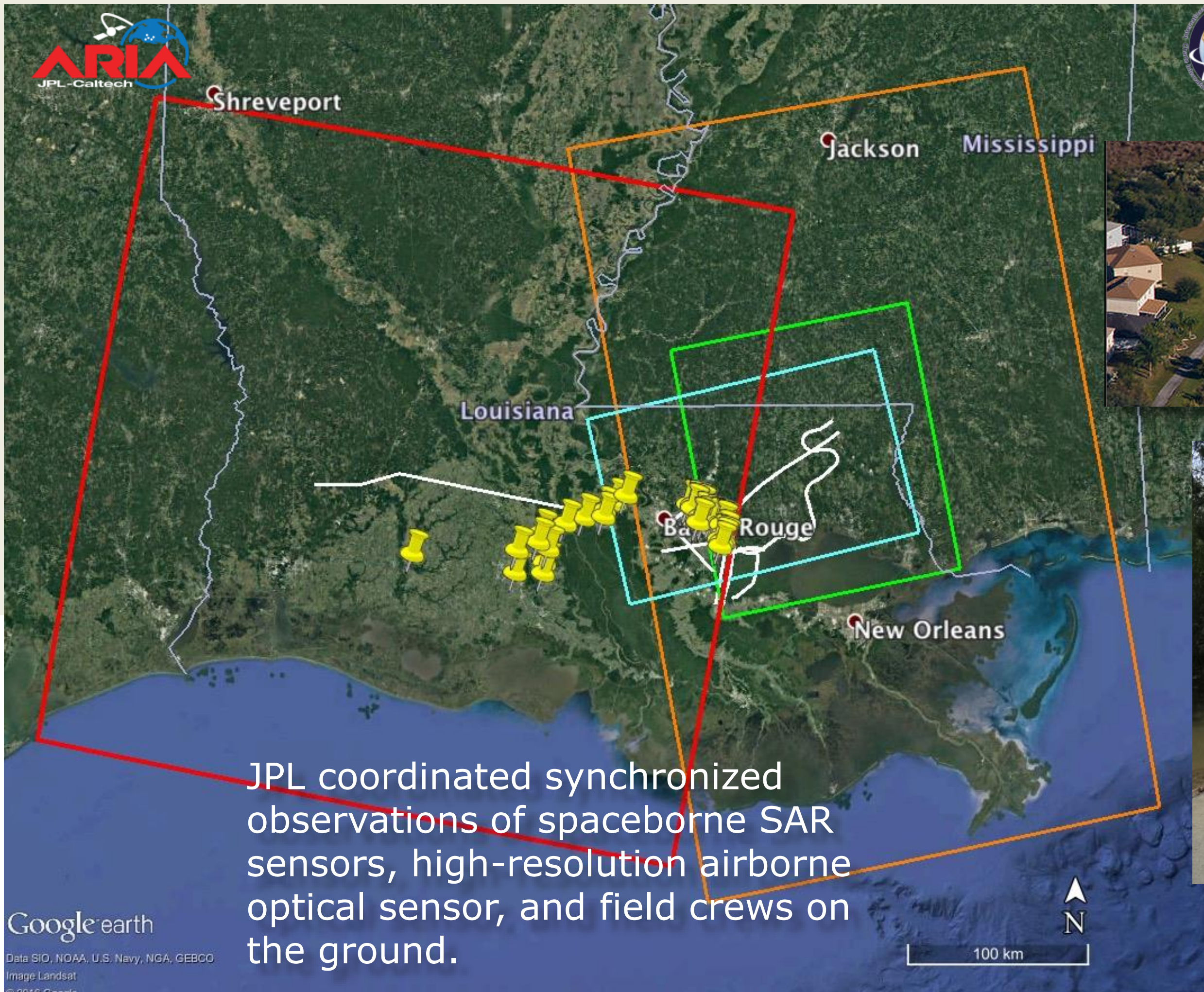


COSMO-SkyMed



RADARSAT–2





JPL coordinated synchronized observations of spaceborne SAR sensors, high-resolution airborne optical sensor, and field crews on the ground.

Photo: Dennis K. Demcheck, U.S. Geological Survey

JPL’s Earth Science Applied Focus Areas
Using radar for society’s benefit

SMAP
Flood and Drought Monitoring

NISAR
Crustal Deformation

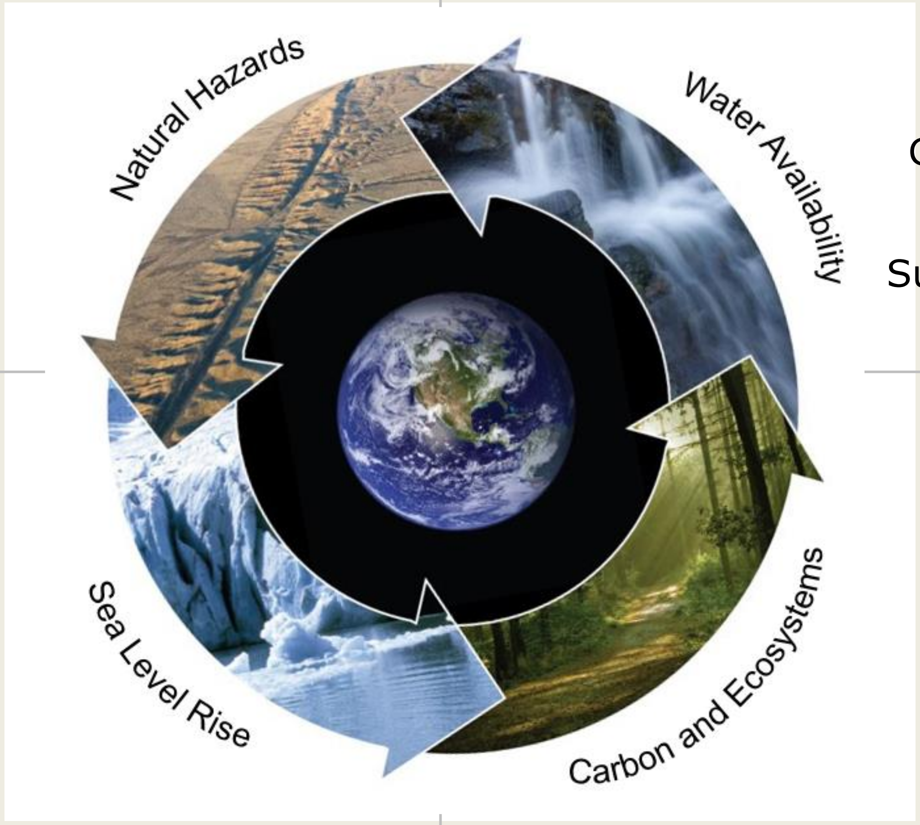
GRACE
Flood Potential

NISAR
Subsidence

ASO
Snow Pack Water

GRACE
Groundwater Storage

SWOT
Surface Water Storage



JASON
Sea Surface Height

NISAR
Ice Sheet Dynamics

GRACE
Ice Mass Balance

SWOT
Mesoscale Dynamics

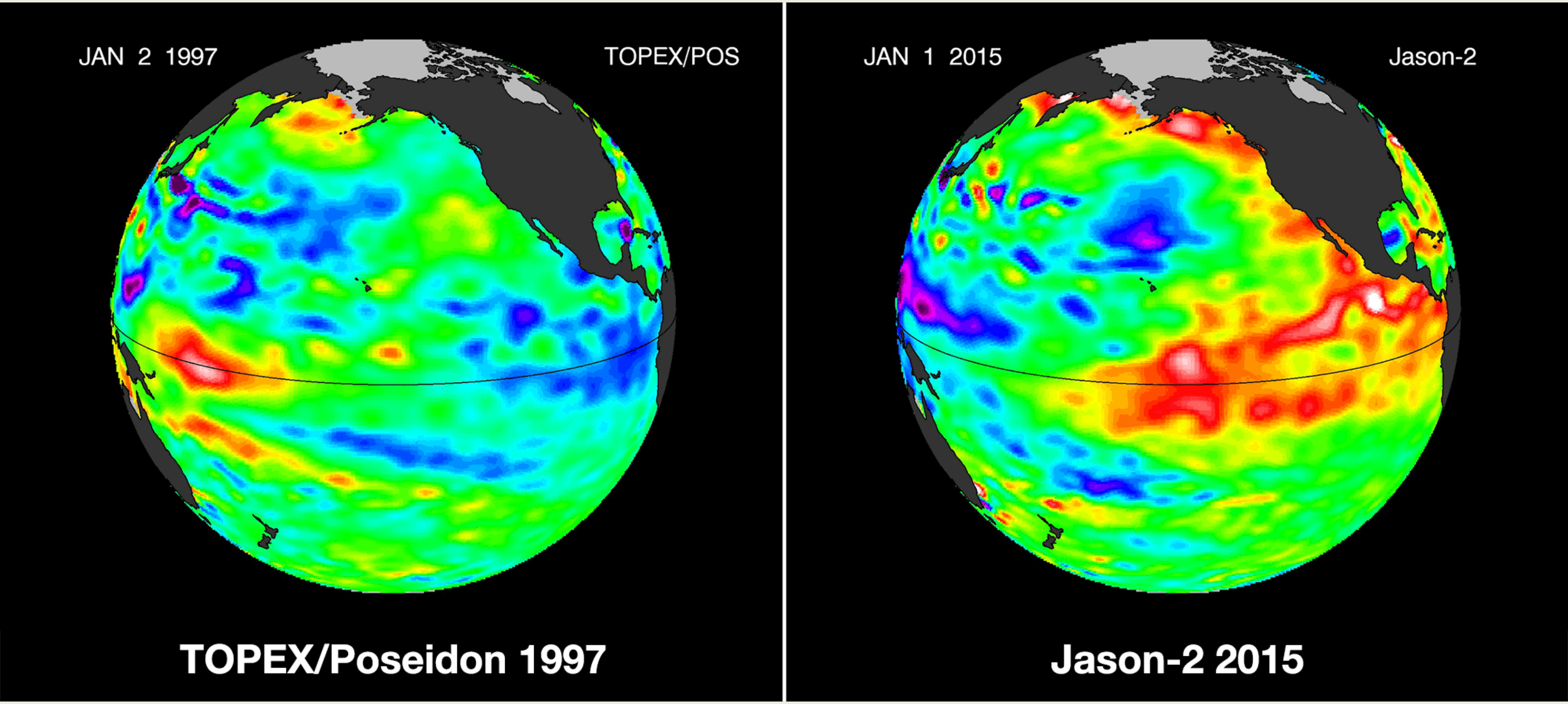
OCO
CO2 Fluxes

NISAR
Biomass Estimates

ECOSTRESS
Plant Health

SWOT
Wetland Extent

The State of El Niño 2015



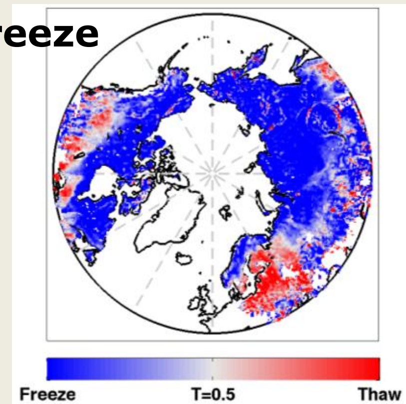
The latest imagery from U.S./European OSTM/Jason-2 satellite reveals the comparative state of current conditions in the Pacific Ocean with the same time period of the last large El Niño event in 1997-98. Eastward propagating warm Kelvin waves are apparent and indicate that the latest wave is sustaining this developing El Niño. *Source; sealevel.jpl.nasa.gov*

JPL

SMAP
Soil Moisture Active/Passive

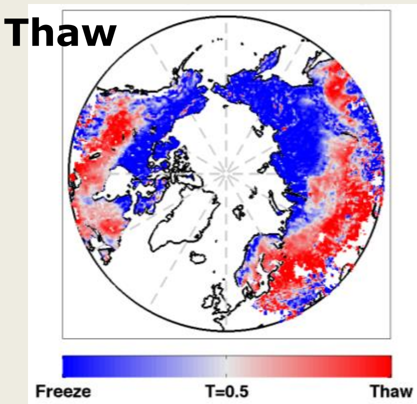
April 1, 2015

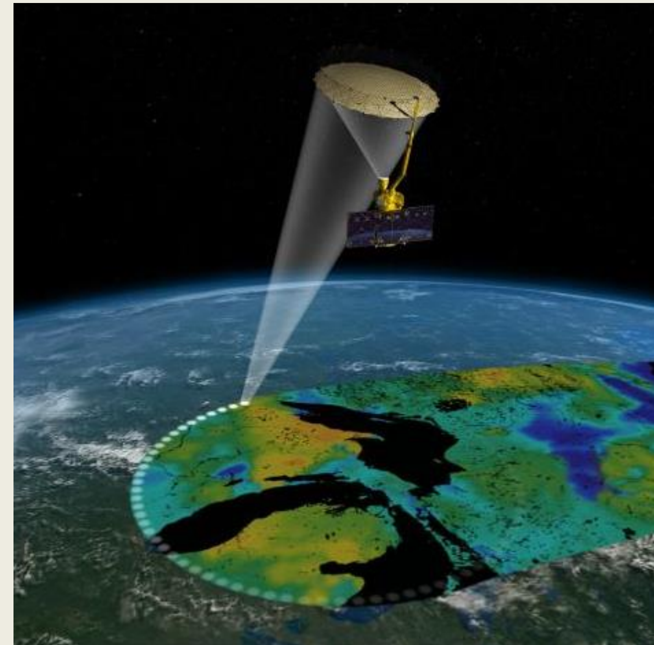
Freeze

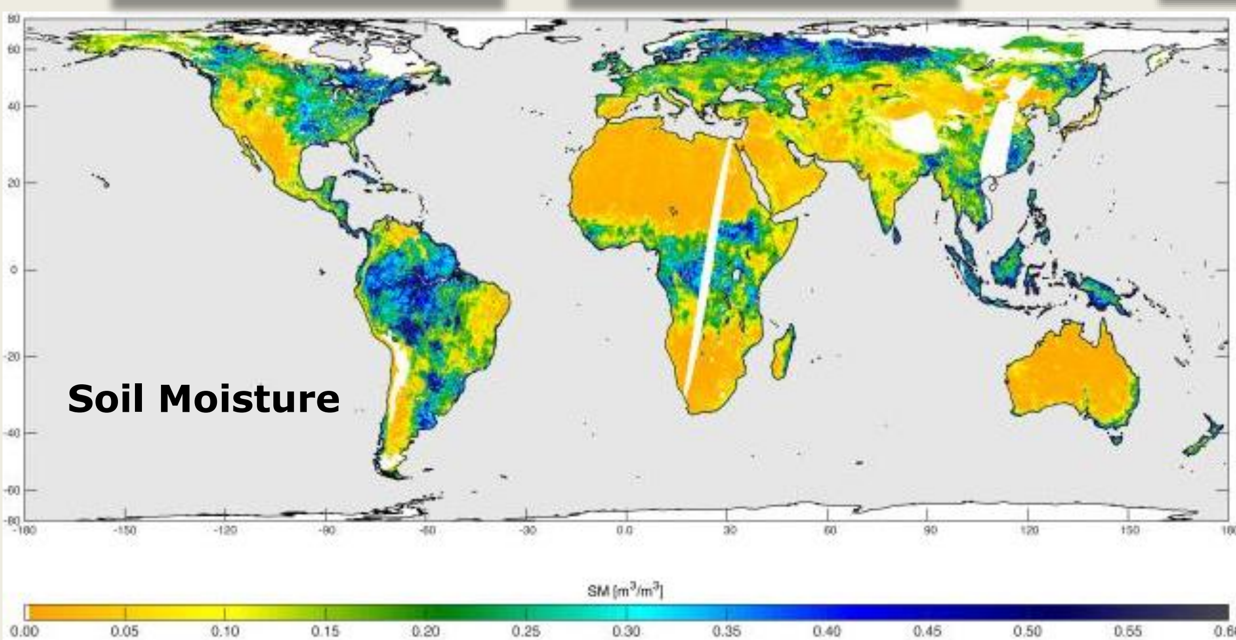


April 13, 2015

Thaw







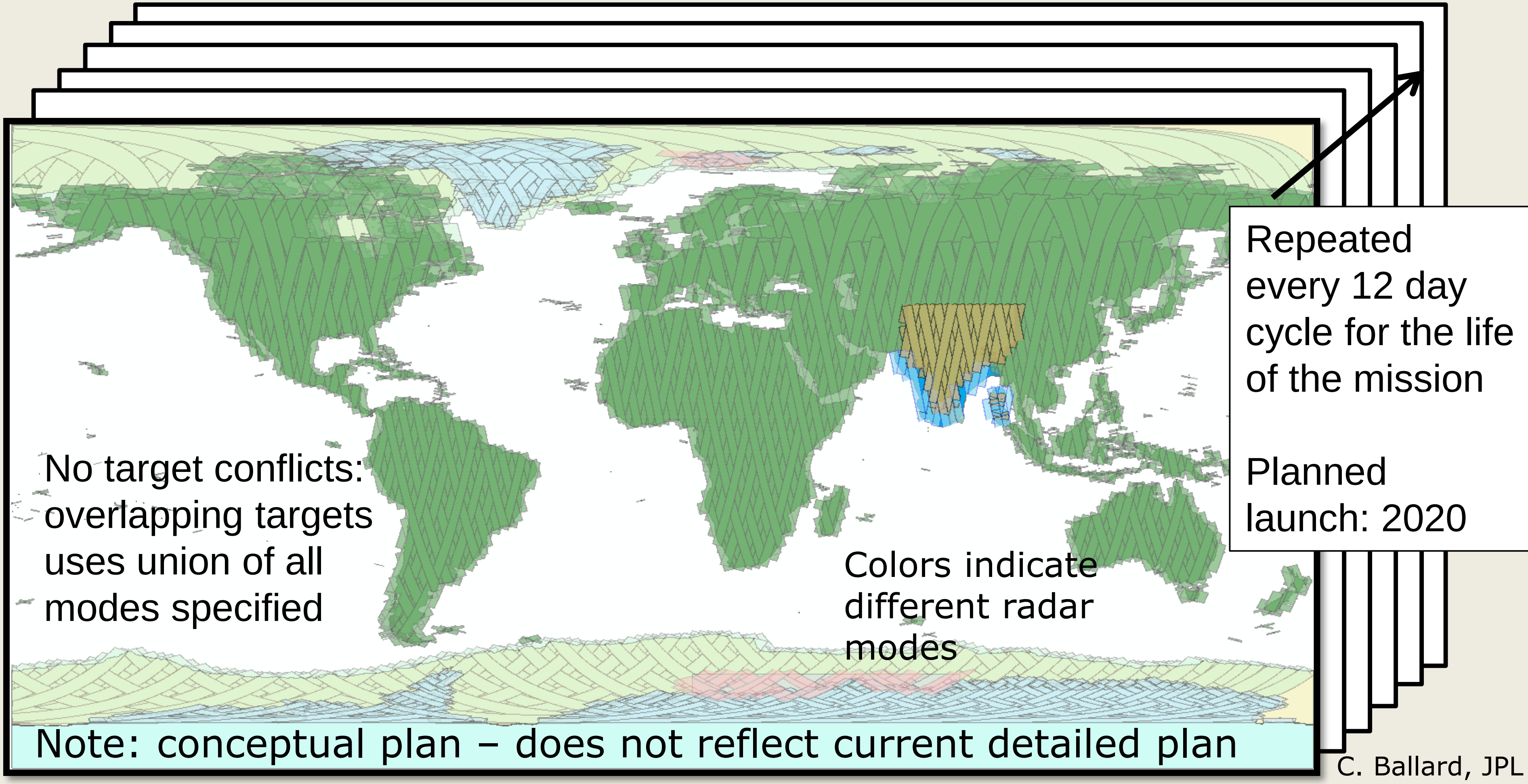
- Three months of unique global L-band radar/ radiometer data

- Continuing radiometer mission

NISAR
NASA-ISRO SAR Mission

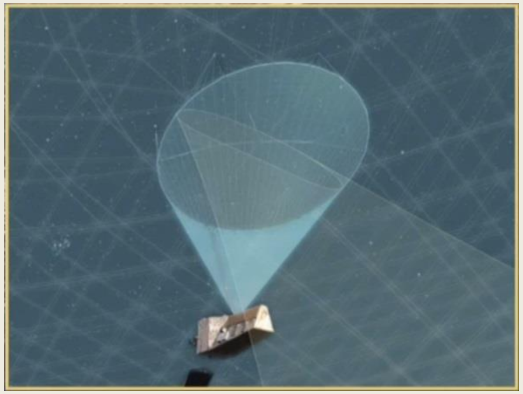
NISAR Characteristic:	**Enables:**
L-band (24 cm wavelength)	*Low temporal decorrelation and foliage penetration*
S-band (12 cm wavelength)	*Sensitivity to light vegetation*
SweepSAR technique with Imaging Swath > 240 km	*Global data collection*
Polarimetry (Single/Dual/Quad)	*Surface characterization and biomass estimation*
12-day exact repeat	*Rapid Sampling*
3 – 10 meters mode-dependent SAR resolution	*Small-scale observations*
Pointing control < 273 arcseconds	*Deformation interferometry*
Orbit control < 500 meters	*Deformation interferometry*
> 50% observation duty cycle	*Complete land/ice coverage*
Left/Right pointing capability	*Polar coverage, north and south*

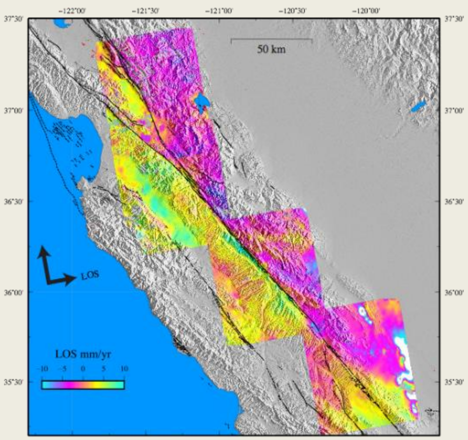
NISAR Systematic Observations L-band globally – S-band selectively

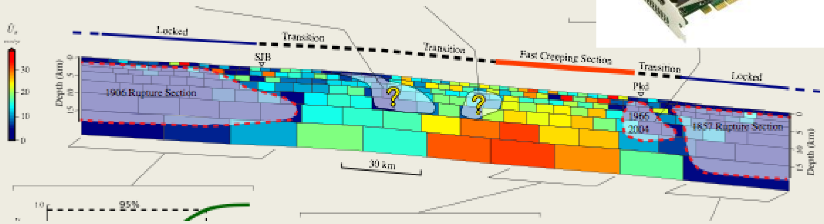


Persistent updated measurements of Earth

Key NISAR Technologies







In Space

- First-of-a-kind wide-swath reflector-based radar
- On-board digital beam forming through high-speed computing devices and self-calibrating electronics

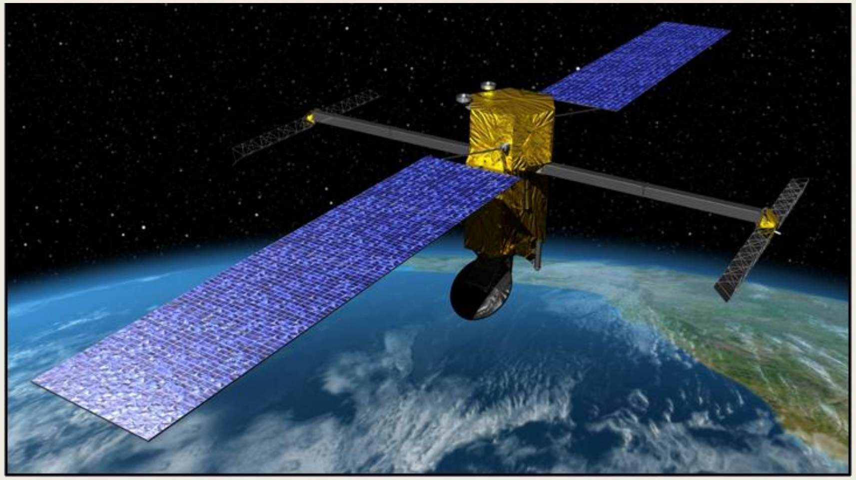
In the Cloud

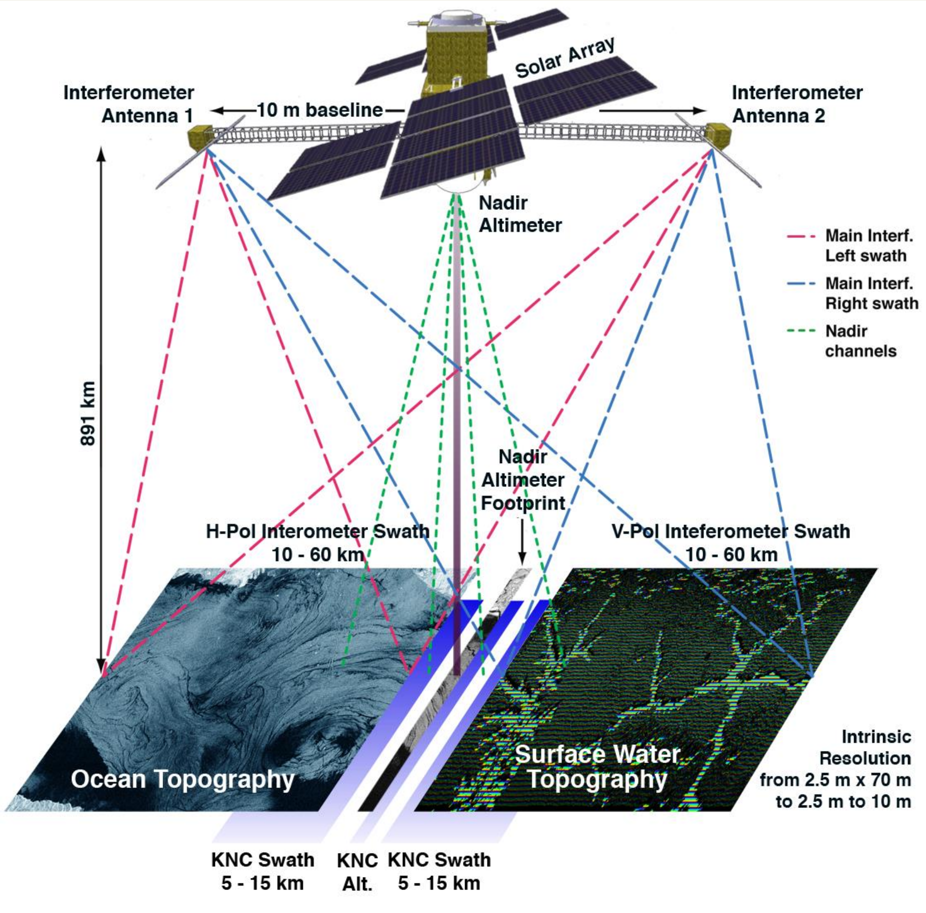
- Petabyte-scale distributed scientific computing of global high-resolution time-series

In the Lab

- GPU-based distributed/cluster computing for solving problems of big coupled systems

Surface Water Ocean Topography (SWOT)



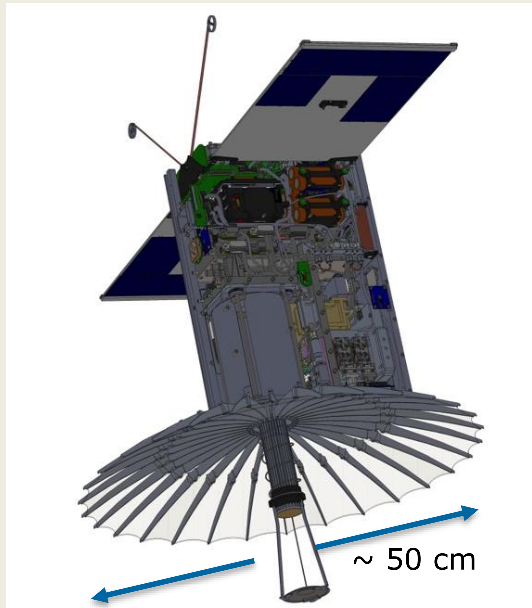


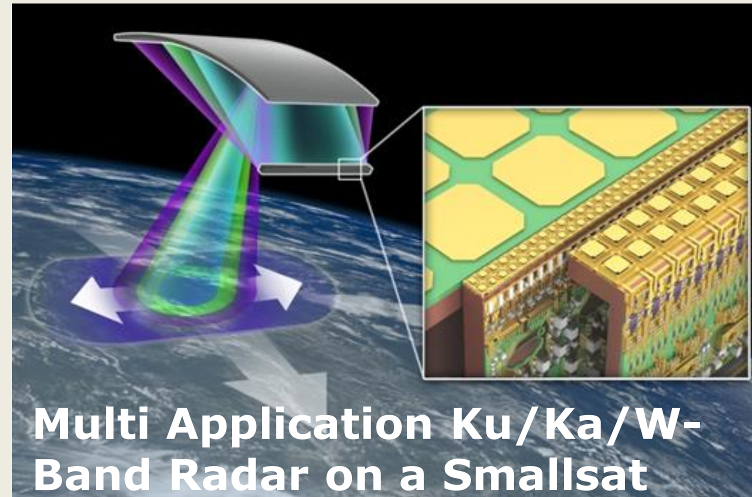
- Planned to launch in October 2020
- Mission Science: Oceanography and Hydrology
- Ka-band interferometry

NASA cnes CSA ASC UK SPACE AGENCY

The Research Renaissance continues…

Raincube Ka-band demonstrator (2018)





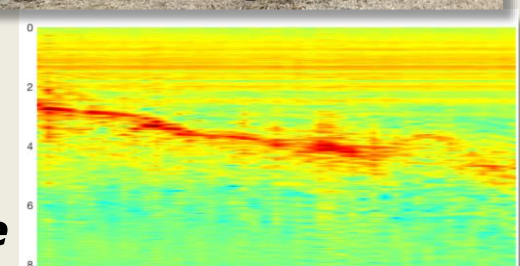
Ka-band DopplerScatt mounted on King Air B200

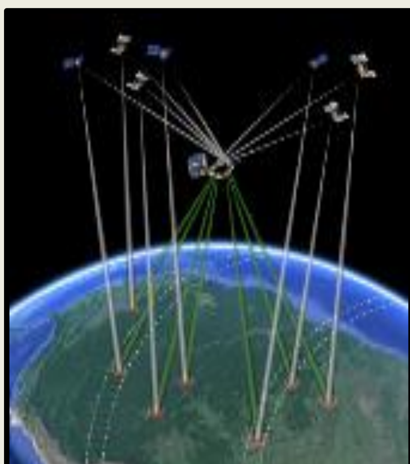
Snowpack Radar X-band Tomographer

Ku- to W-band atmospheric sounders

The Research Renaissance continues…

AirSWOT and UAVSAR
L-/P-/Ka-bands
Repeat- and Single-pass
Interferometry

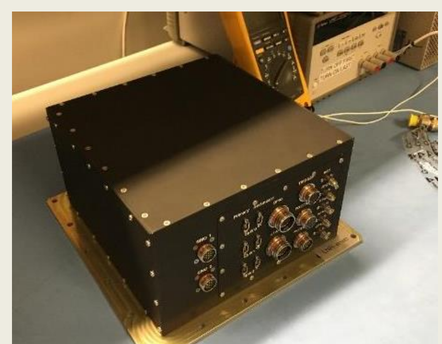


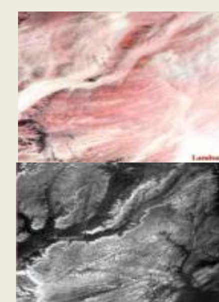


GNSS Reflections for
land surface properties

Drone-based GPR

Multi-Mission Subsurface
Imaging UHF Radar
Earth
Mars
Moon
Asteroids
Comets

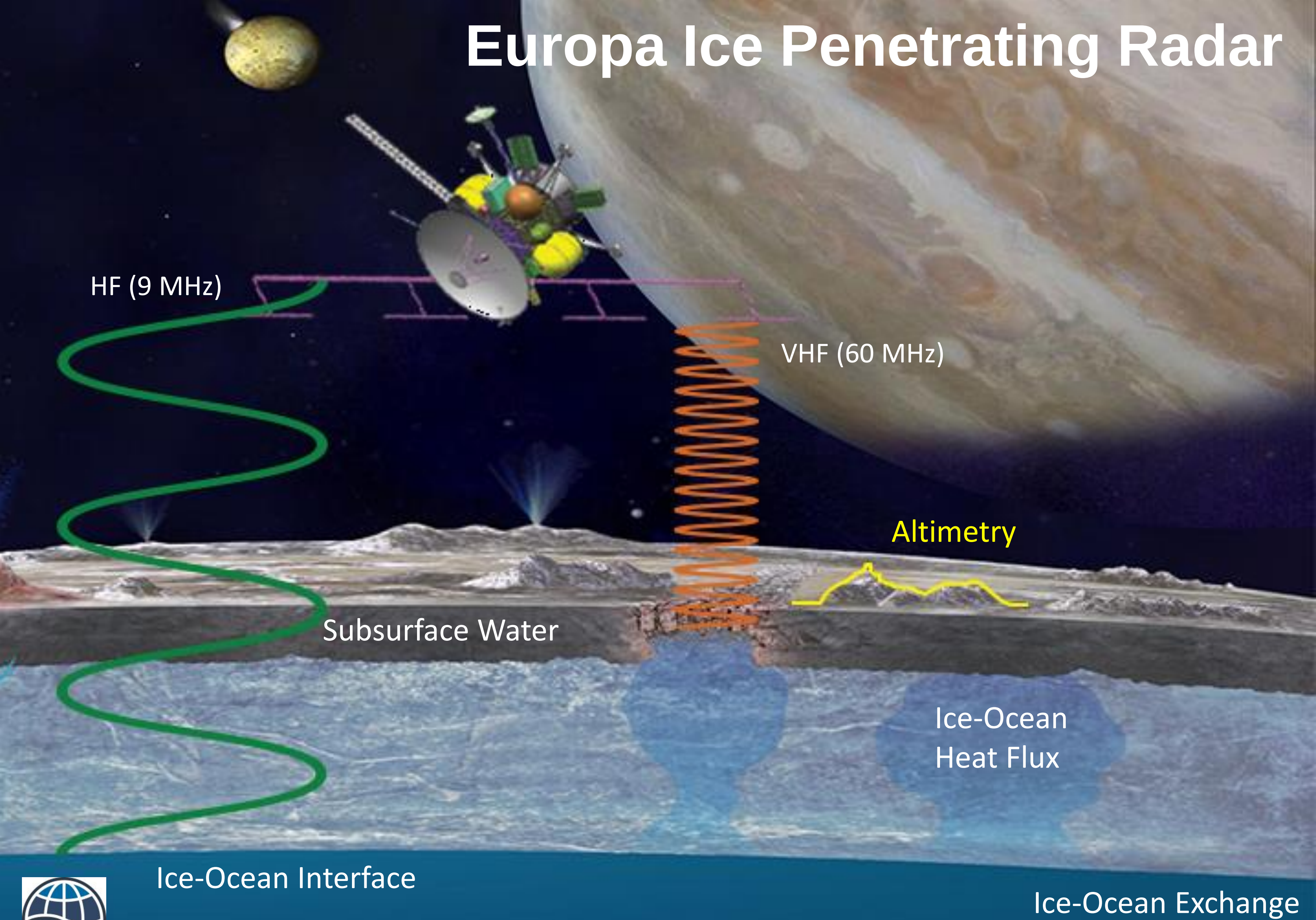




The Future - Enlightenment?

- Agency-led facility instruments for science and applications
- Commercial radar smallsats for specialized applications
- Tidal wave of data requiring new data analysis and information retrieval paradigms

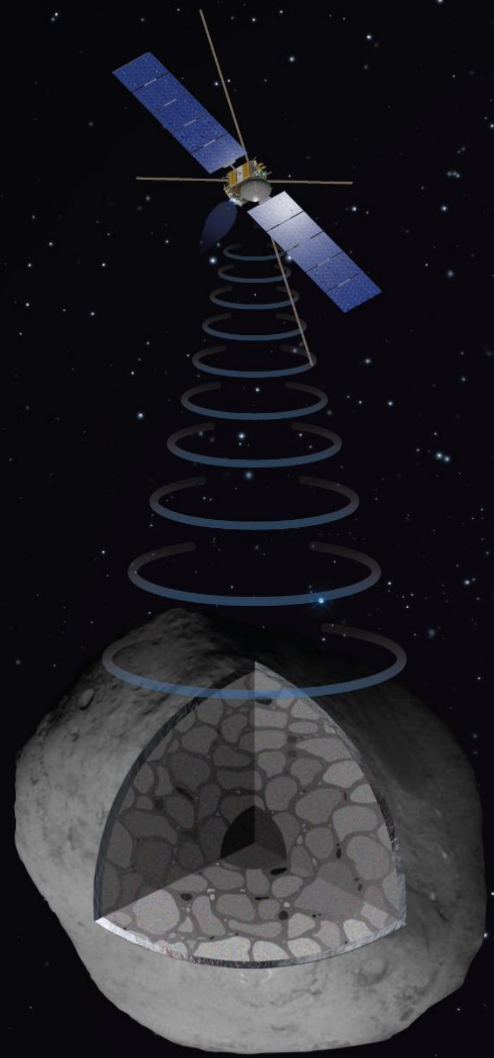
Europa Ice Penetrating Radar



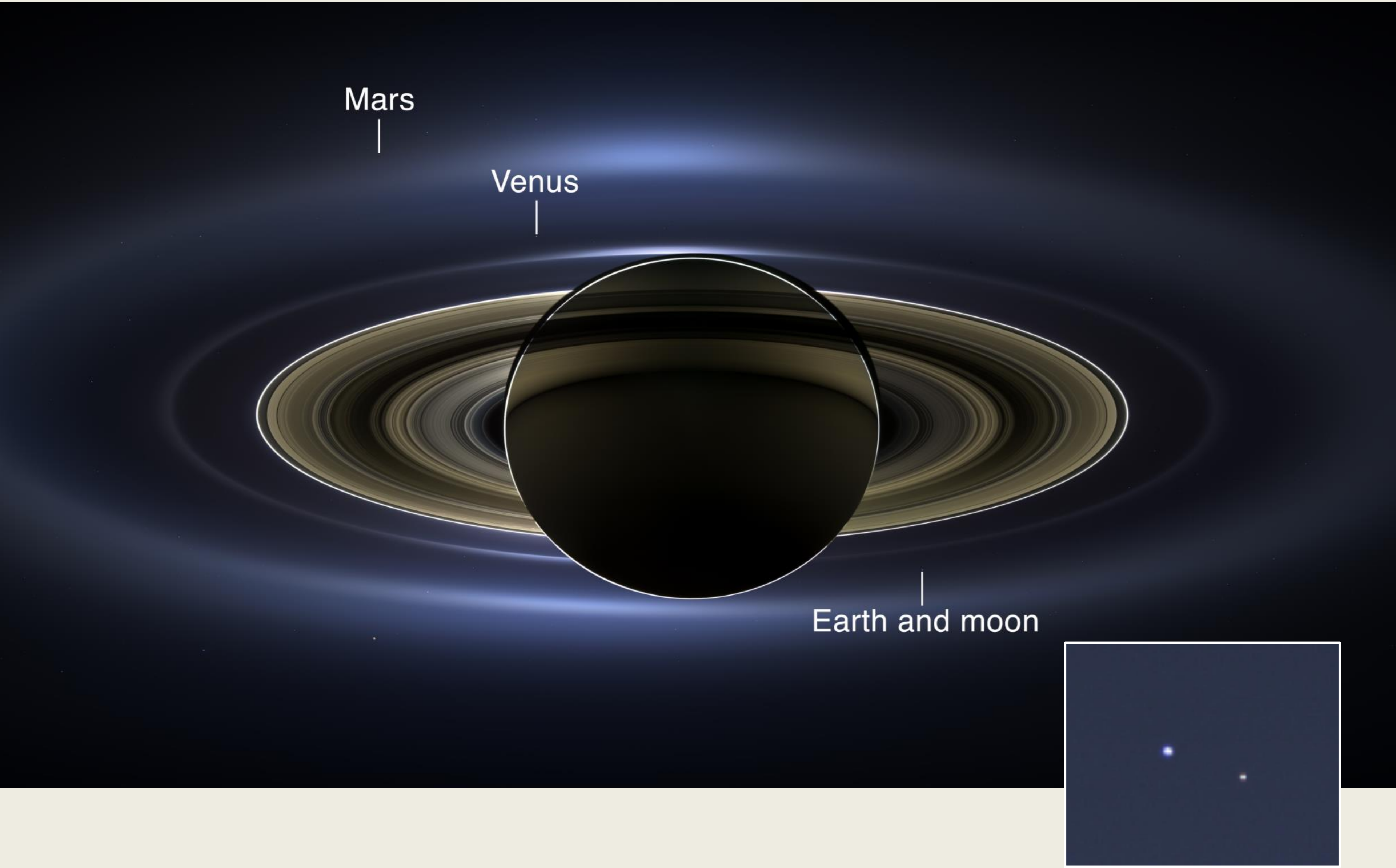
UTIG

RIME and REASON to Europa and Ganymede

CORE (Comet Radar Explorer) Mission Concept



Explore the cometary nucleus


Mars
Venus
Earth and moon

Acknowledgments

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- Dr. Scott Hensley, JPL
- Radar colleagues around the world

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